JUN 17 1933

Volume 17 JUNE, 1933 Number 6

BULLETIN
of the
American Association *of* Petroleum Geologists

CONTENTS

Review of Tertiary Stratigraphy of Louisiana *By Henry V. Howe* 613

Structure and Stratigraphy, Kelsey Anticline, Upshur County, Texas *By A. R. Denison, A. E. Oldham, and J. W. Kisling, Jr.* 656

Results of Structural Research Work in Beartooth-Bighorn Region, Montana and Wyoming *By W. H. Bucher, R. T. Chamberlin, and W. T. Thom, Jr.* 680

Analysis and Effects of Current Movement on an Active Fault in Buena Vista Hills Oil Field, Kern County, California *By Thomas W. Koch* 694

Rôle of Cap Rock in Oil Accumulation *By Robinson P. Lockwood* 713

GEOLOGICAL NOTES

Long Beach, California, Earthquake of March 10, 1933 *J. Edmund Eaton* 732

Cracks Produced by Long Beach, California, Earthquake *Donuil Hillis* 739

Projection of Dip Angle on Profile Section *Stanley C. Herold* 740

Suggested Research on Origin of Petroleum *F. M. Van Tuyl and Ben H. Parker* 743

Kincaid Formation, Name Proposed for Lower Midway of Texas *Julia Gardner* 744

REVIEWS AND NEW PUBLICATIONS

The Lower York-James Peninsula *Joseph K. Roberts* (Julia Gardner) 748

Recent Publications 748

THE ASSOCIATION ROUND TABLE

Membership Applications Approved for Publication 750

Association Committees 751

MEMORIAL

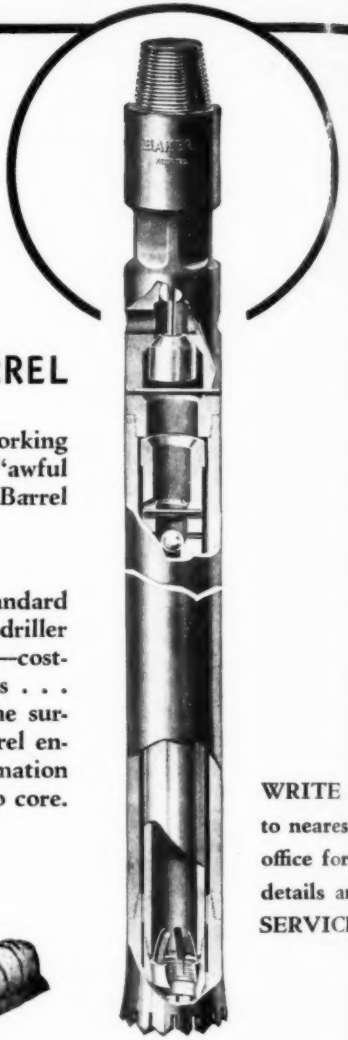
Eugene Crittenden Templeton *Harry R. Johnson* 752

AT HOME AND ABROAD

Current News and Personal Items of the Profession 753

COPYRIGHT, 1933, BY THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

TRIED
and found TRUE
the BAKER
CABLE TOOL CORE BARREL



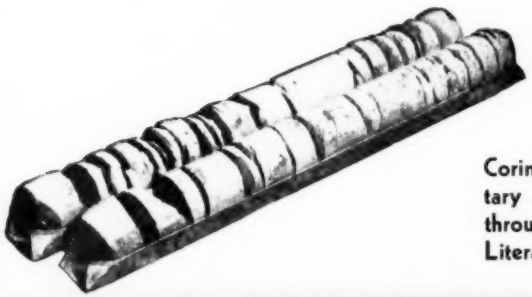
In locations all over the world, working under conditions from "easy" to "awful tough," the BAKER Cable Tool Core Barrel has been tried and found true.

It always makes good.

It is the *answer* to the Geologist's standard coring problems. So practical that any driller can use it successfully . . . economical—costing but little more than ordinary bits . . . Bringing unusually perfect cores to the surface, the Baker Cable Tool Core Barrel enables you to secure dependable information for every foot of the hole you desire to core.

It is thoroughly trustworthy.

WRITE to nearest office for details and SERVICE



Coring problems . . standard or rotary . . will be carefully attended to through personal correspondence. Literature on request.

BAKER OIL TOOLS, INC.

HUNTINGTON PARK, CALIFORNIA

COALINGA · TAFT · HOUSTON · OKLAHOMA CITY · TULSA · NEW YORK

Please use coupon on last page of advertisements in answering advertisers

Volume 17 Number 6

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

JUNE, 1933

REVIEW OF TERTIARY STRATIGRAPHY OF LOUISIANA[1]

HENRY V. HOWE[2]
Baton Rouge, Louisiana

ABSTRACT

The great thickness of the Tertiary sediments in Louisiana has only recently been appreciated. As Louisiana has not possessed a geological survey for the past 25 years, information concerning the stratigraphy of the state has appeared in many scattered publications. This paper is an attempt to bring such information together in a convenient summary. Original definitions of groups, formations, and members are quoted and footnote references are given to the more important papers dealing with the stratigraphic nomenclature and paleontology of the Tertiary of the state. The writer has presented evidence to show that the Eocene group name "Wilcox" should be abandoned in favor of the name "Sabine." He also suggests that the so-called "Middle Oligocene" "*Discorbis*, *Heterostegina*, and *Marginulina* zones" of the salt-dome section of south Louisiana should be correlated with the Miocene "Tampa limestone" of Florida as the marine equivalent of the Catahoula sandstone.

INTRODUCTION

Comparatively few of the stratigraphic names currently used to designate Louisiana formations originated in Louisiana or have their type sections in that state. Moreover, Louisiana is probably fortunate in the fact that several of her major groups have not been split into a myriad of improperly defined and confusing subdivisions. Much of the major work which accompanies accurate stratigraphy is yet to be done and, if future studies are made with the precision now known to

[1] Read before the Association at the Houston meeting, March 23, 1933. Decision as to whether the term "Wilcox" (proper use of which is questioned in this article) shall be continued, due to its common usage, or whether the term "Sabine" shall be reintroduced because of its priority and better type locality, has been submitted to the committee on stratigraphy of the National Research Council, Washington, D. C. The author is in favor of following the decision of the committee. Notice of this decision will be published in the *Bulletin*.—A.A.P.G. committee on geologic names and correlations.

[2] Louisiana State University.

be needed, the major groups present in Louisiana may yet furnish the type sections for many minor subdivisions.

The writer makes no pretense of presenting a complete survey of Louisiana stratigraphic nomenclature. Such a survey is scarcely possible at the present time due to the vast number of stratigraphic units which, during the past 150 years, have been used either properly or improperly to delineate the formational sequence of the Tertiary of the Gulf Coast.

This review is, instead, an attempt to give something of a picture of the major formational units present, with a brief mention of the lithologic character, thickness, and subdivisions of each.

Eocene Period

Midway group[1]

The writer believes that the first use of the term "Midway" in referring to Louisiana formations was made by Harris and Veatch.[2] They gave two localities: Rocky Springs church in Sabine Parish and King's salt works in Bienville Parish. The present writer[3] subsequently showed the first locality to lie in the Sabine, and Spooner[4] failed to observe Midway fossils at Kings, and his map does not show it cropping out there.

During the 20 years following the mention of Midway by Harris and Veatch, many papers appeared in which the term Midway was mentioned in well-log correlation. In most cases the horizon referred to in the well logs belonged to the lower part of the Sabine and the true Midway was assigned to the Arkadelphia, as was noted by Hull.[5] In this paper Hull indicated that Midway was actually exposed on the Bistineau and Vacherie salt domes in Webster Parish and on the Prothro dome in Bienville Parish. Further discussion of Midway distribution in Louisiana has appeared in papers by Howe,[6] Spooner,[7]

[1] Named for Midway Landing, on Alabama River, Alabama. For details of type section see: C. Wythe Cooke, "The Cenozoic Formations," *Alabama Geol. Survey Spec. Rept. 14* (1926), pp. 251–97, especially pp. 253–56 and Pl. 93.

[2] G. D. Harris and A. C. Veatch, "The Geology of Louisiana," *Louisiana Geol. Survey Rept.* (1899), pp. 64–84.

[3] H. V. Howe, " 'The Many Salt Dome,' Sabine Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (January–February, 1925), pp. 170–71.

[4] W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), pp. 217–92; *ibid.*, *Geology of Salt Dome Oil Fields* (1926), pp. 269–344.

[5] J. P. D. Hull, "Guide Notes on the Midway in Southwestern Arkansas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (January–February, 1925), pp. 167–70.

[6] H. V. Howe, "Extension of Midway Formation into Louisiana," *Pan-Amer. Geol.*, Vol. 43, No. 4 (1925), p. 309.

[7] W. C. Spooner, *op. cit.*, pp. 232–33.

and Moody.[1] Moody's excellent picture of Midway sedimentation is quoted as follows.

It has been known for many years that a long period of time elapsed between the termination of Cretaceous deposition and the accumulation of the earliest Tertiary deposits. The evidence has been largely paleontologic. Recent drilling in eastern Louisiana and central Mississippi has, however, furnished remarkable physical evidence of the reality of this hiatus. Development of the Richland gas field has shown that the basal Tertiary lies on an erosional surface in which strata ranging in age from late Cretaceous to early Comanche have been truncated to form the floor on which the deposits of the Midway sea were built up. On the Jackson anticline in Mississippi the Midway lies on early Cretaceous beds and in Sharkey County the same formation lies directly on igneous rock of andesitic composition the age of which is unknown. This heterogeneity of the floor over which the waters of the Midway sea were spread points clearly to a complex history in the time intervening between the cessation of Mesozoic deposition and the return to marine conditions at the dawn of Tertiary time.

Great likeness exists between the sedimentary material of the basal Tertiary and the latest Cretaceous. The dark, steel-gray, shaly clays of which the Midway is largely composed, closely resemble the fine sediments of the Navarro of Texas, the Arkadelphia of Arkansas, and certain phases of the Ripley-Selma of Mississippi and Alabama. The lower part of the Midway group is chiefly calcareous, with true chalk occurring as lenses in Arkansas and Louisiana, which lenses are doubtless transitional from the Clayton limestone of the Alabama section to the Tehuacana limestone of northeast Texas. This calcareous Midway contains a well known marine invertebrate fauna. In later Midway time, limy material reached the sea in less and less quantity until only finely divided terrigenous detritus was deposited. Marine life also became gradually more impoverished and finally ceased to exist in the embayment region. It is noteworthy that siderite concretions were formed in profusion in the dark Midway clays. Their occurrence marks the end of the great Cretaceous cycle of calcareous deposition in the Gulf Embayment region and may be considered as inaugurating the period of iron deposition which culminated in the Claiborne. Two important conclusions may safely be drawn from a study of the physical character of the Midway beds: (1) the materials of the Midway and of the late Cretaceous formations were derived from essentially the same source under similar climatic and topographic conditions; (2) during Midway time the earth's crust was remarkably stable throughout hundreds of thousands of square miles in the Gulf Coastal Plain, being slowly and uniformly depressed while 600 feet of homogeneous mud was accumulating on the sea floor. Cessation of this crustal stability brought Midway deposition to a close and forced the Gulf shore back toward the continental shelf.

Recent papers have supplied information concerning the thickness of the Midway at a number of points in North Louisiana. The most

[1] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 531–51.

abundant references deal with Caddo Parish in the northwestern part of the state where Fletcher[1] gives the thickness for the Caddo field as a whole as 600–700 feet. Crider,[2] however, reduced the thickness at Pine Island to 550 feet, and Shearer and Hutson[3] show the Midway to have a thickness of 300–400 feet in the region of the Dixie oil field. Farther east, Ross[4] gives the thickness as 600 feet in the Cotton Valley field and Spooner[5] reports 450 feet of Midway at Homer in Claiborne Parish. Still farther east Gordon[6] has reported a thickness of 600 feet for the Midway in the region of Richland Parish. And farther south, in the neighborhood of the Angelina-Caldwell flexure, Shearer[7] states:

> The Standard Oil Company's Tremont Lumber Company No. 1, in Sec. 1, T. 12 N., R. 2 W., Winn Parish, . . . had a thickness of 2363 feet of Wilcox and Midway, of which at least 1,385 (possibly 1,564) feet was Wilcox.

This gives a thickness for the Midway of either 978 or 799 feet—a figure considerably in excess of that recorded farther north in the state.

Few fossils have been described from the Midway of Louisiana, but excellent papers are available which delineate the faunas from adjacent states. The principal monographs describing Midway fossils are by Harris,[8] Vaughan,[9] Clark and Twitchell,[10] and Mrs. Plummer.[11]

[1] C. D. Fletcher, "The Caddo Field, Caddo Parish, Louisiana," *Structure Typical American Oil Fields*, Vol. 2 (1929), p. 188.

[2] A. F. Crider, "Pine Island Deep Sands, Louisiana," *Structure Typical American Oil Fields*, Vol. 2 (1929), p. 170.

[3] H. K. Shearer and E. B. Hutson, "Dixie Oil Pool, Caddo Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 6 (June, 1930), pp. 747–49.

[4] J. S. Ross, "Engineering Report of Cotton Valley Field, Webster Parish, Louisiana," *U. S. Bur. Mines Tech. Paper 504* (1931), p. 7.

[5] W. C. Spooner, "Homer Oil Field, Louisiana," *Structure Typical American Oil Fields*, Vol. 2 (1929), p. 200.

[6] D. Gordon, "The Richland Gas Field, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 8 (August, 1931), p. 943.

[7] H. K. Shearer, "Geology of Catahoula Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), p. 444.

[8] G. D. Harris, "The Midway Stage," *Bull. Amer. Paleont.*, No. 4 (1896). 157 pp.

[9] T. W. Vaughan, "The Eocene and Lower Oligocene Coral Faunas of the United States," *U. S. Geol. Survey Monogr. 39* (1900). 263 pp.

[10] W. B. Clark and M. W. Twitchell, "The Mesozoic and Cenozoic Echinodermata of the United States," *U. S. Geol. Survey Monogr. 54* (1915). 341 pp.

[11] H. J. Plummer, "*Foraminifera* of the Midway Formation in Texas," *Univ. Texas Bull. 2644* (1926). 206 pp.

SABINE GROUP[1]

Veatch,[2] in 1906, gave a detailed description of the group, which is quoted here.

Overlying the Midway limestones and calcareous clays is a series of dark finely laminated sands and clays containing much vegetable matter, either scattered through the mass or accumulated in lignite beds, and occasional layers containing marine shells. It commonly differs from the underlying Midway in the presence of lignitic material and fossil leaves and when containing marine fossils it is readily distinguished from both the Midway and the overlying Claiborne. Toward the coast, where it is overlain by the very calcareous, argillaceous, fossiliferous, lower Claiborne beds, its upper limit can be fixed with exactness, but farther inland, where estuarine and swamp conditions persisted until Jackson time, no separation is possible except on a purely stratigraphic basis.

On the whole, the formation is predominantly sandy, and while the sand beds are not so regular or so coarse as some of the beds in the Cretaceous, they are the most important water-bearing strata in Louisiana and Arkansas north of the outcrop of the Catahoula formation and south of the Eocene-Cretaceous boundary.

In Alabama this formation, which has long been called the Lignitic, contains several fossiliferous horizons that are closely related from a paleontologic standpoint, but show faunal differences which have led to the recognition of four substages, named as follows, beginning with the lowest: (1) Nanafalia, (2) Bells and Greggs landings (Tuscahoma), (3) Woods Bluff, and (4) Hatchetigbee. The first two are sometimes collectively called the Bells Landing substage and the second two the Bashi substage. No distinctive marine fossils have yet been found in the lignitiferous time equivalents of this formation in Mississippi, Arkansas, and the upper embayment region, but along Sabine River in Louisiana and Texas, in the same position relative to the embayment as the Alabama deposits, are developed fossiliferous beds showing the same facies. *Ostrea thirsae*, an oyster common in the Nanafalia horizon in Alabama, occurs in abundance at Marthaville, La., and the fossils from Pendleton and Sabinetown bluffs on Sabine River, in Sabine County, Tex., show very close affinities to the Greggs Landing and Woods Bluff horizons of Alabama. These beds are limited above by a well-preserved and abundant lower Claiborne fauna, and below by the Midway (Wills Point) fossiliferous clays and limestones.

The name Lignitic formation, derived from the lithologic character of the beds, is not in accordance with the rules of geologic nomenclature, and it is therefore necessary to give to this formation the name of some locality at or near which the beds are typically exposed. As the name Chickasaw formation or stage, which has been used by Dall as an exact synonym for Lignitic, is neither stratigraphically nor historically appropriate in this sense, and as the

[1] Originally used by A. C. Veatch, "The Underground Waters of Northern Louisiana and Southern Arkansas," *Louisiana Geol. Survey Bull. 1* (1905), pp. 84–85, to replace the name "Lignitic."

[2] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), pp. 34–36.

name Lagrange (Safford, 1864) has been applied to the lignitiferous complex above the Midway, and as the doubtful definition and the lack of marine fossils at the type localities of the Mansfield group (Hilgard, 1873) and the Camden formation (Hill, 1888) make them unavailable, the name Sabine has been suggested and adopted, from the typical development of the formation along Sabine River in Sabine County, Tex., and Sabine Parish, La., and from noteworthy exposures at Sabinetown Bluff.

The Sabine formation and its equivalent beds in the undifferentiated Eocene underlie the whole of Louisiana, except the limited areas occupied by the outcrops of the Cretaceous and Midway domes, and all of Arkansas south and east of the Cretaceous and Midway outcrops. Its thickness, as shown by carefully constructed sections in which local irregularities are reduced to their proper minor importance, ranges from 300 feet in northern Bossier Parish to from 800 to 900 feet near Natchitoches and on Sabine River.

During the past fifteen years, most writers, including the present one, have used the name "Wilcox" when referring to sediments belonging to this group. This name was apparently first used by Crider and Johnson[1] but appeared also in another paper by Crider[2] and is usually attributed to his authorship. From the former paper the following explanation of the origin of the term is taken.

> The term "Lignitic" as used by Hilgard has been objectionable because it is not a locality name. As used by Safford the term "La Grange" included the present Lafayette and portions of the Cretaceous so it has likewise been discarded. The present name, Wilcox, was first given in some unpublished work by Eugene A. Smith, State geologist of Alabama, for the reason that typical strata of the former Lignitic of Hilgard are exposed at Wilcox, Ala. The name has been adopted by the United States Geological Survey as the formation name to include the complex mass of sands, clays, lignites, marls, etc., between the Porters Creek clay below and the Tallahatta buhrstone above.

Both the paper by Crider and Johnson and that by Crider were published in 1906. It makes no difference which happened to come off the press first, for the foregoing explanation of the name Wilcox clearly shows that it is the intention of the authors to name the formation for an exposure "*at Wilcox, Alabama.*" Later authors have stated that the group was named for Wilcox County, Alabama, but there is no mention of that county in either description, and *it is clearly evident that Crider and Johnson had no such intention.* The writer has searched the State Geologic Map of Alabama[3] in vain to find any town or vil-

[1] A. F. Crider and L. C. Johnson, "Summary of the Underground Water Resources of Mississippi," *U. S. Geol. Survey Water-Supply Paper 159* (1906), p. 9.

[2] A. F. Crider, "Geology and Mineral Resources of Mississippi," *U. S. Geol. Survey Bull. 285* (1906), p. 25.

[3] "Geology of Alabama," *Alabama Geol. Survey Special Rept. 14*, prepared in coöperation with the U. S. Geol. Survey, 1926.

lage by the name of "Wilcox" within the area assigned on the map to the "Wilcox group," nor is it listed in the *United States Official Postal Guide*, 4th. ser., Vol. 12, No. 1, July, 1932. It is well to note at this point that the use of "Wilcox County" for a type locality or even a type section is not appropriate, for all four of the Alabama formations belonging to the group have their type sections in other counties. The Nanafalia formation is named for Nanafalia Landing, in Marengo County; the Tuscahoma sand is named for Tuscahoma Landing, Sec. 31, T. 13 N., R. 1 W., Choctaw County; the Bashi formation is named for Bashi Creek, a tributary of Tombigbee River in northern Clarke County; and the Hatchetigbee formation is named for Hatchetigbee Bluff on the Tombigbee River in Washington County.[1]

To show clearly that the name "Wilcox" is both inappropriate and lacks priority, the writer quotes the following comment from a paper by Harris,[2] the dean of Gulf Coast stratigraphers, which is certainly well taken and timely.

> *Sabine Stage.*—Now known as the *Sabine stage* from the river by that name separating Sabine County, Texas, and Sabine Parish, La., and showing good fossiliferous outcrops along its banks. Exception has been taken to the name Sabine since Penrose made use of the expression "Sabine River beds" to include certain horizons not included within the stage as now defined. This use of a descriptive expression can scarcely invalidate the clearly defined name proposed by Veatch and sanctioned by the proper authorities of the U. S. Geological Survey. The name Wilcox, since used by that bureau, lacks priority and is based on an obscure county name in Alabama, one that in no way carries the historical significance of Sabine, nor would it be found on general maps of the United States.

The contention of some, which Harris refers to, that the name Sabine formation or Sabine group as clearly defined by Veatch is invalidated by the previous use by Penrose of the expression "Sabine River Beds" is found to be utterly ridiculous when the paper by Penrose in the First Annual Report of the Geological Survey of Texas is examined. In that paper, under the descriptive chapter heading "THE TIMBER BELT OR SABINE RIVER BEDS," he proceeds to discuss the greater portion of East Texas which is covered by timber (pages 22–47). The writer quotes from his initial paragraph (p. 22) the following sentences which clearly show that Penrose was not in any way intending to name a formation.

[1] The location of the type sections of these formations is taken from *Alabama Geol. Survey Special Rept. 14* (1926).

[2] G. D. Harris, "Pelecypoda of the St. Maurice and Claiborne Stages," *Bull. Amer. Paleont.* Vol. 6 (1919), pp. 5–6.

The Basal Clays, everywhere from the northern part of the State to the Colorado River, blend upwards into the sandy Timber Belt Beds. *These form the mass of the Tertiary formation in Texas,* and underlie the great timber region of the eastern part of the state. . . . These beds occupy an area over 125 miles wide in the northeast part of the State, but thin down to less than 40 miles on the Colorado.

In the following 25 pages of description, he frequently makes use of the descriptive expression "Timber Belt Beds," but there is no attempt to give a type section and, aside from the title, the expression "Sabine River Beds" appears not one single time.

While the points made by Harris are conclusive and clearly show that the name "Wilcox" should be discarded, recent drilling operations have demonstrated that the "Wilcox section" of Alabama represents only the upper portion of the Sabine group present in Sabine County, Texas, and Sabine Parish, Louisiana. Moody[1] has recently shown the group to have a thickness of at least 3,000 feet along the line of the Angelina-Caldwell flexure where it crosses the Sabine River, and the writer[2] has shown that there are more than 1,300 feet of sediments attributable to this group below beds which carry *Ostrea tasex* Gardner, a characteristic fossil of the Indio formation, the basal member of this group in southwest Texas. Recent wells drilled near Marthaville, Louisiana, and in the Zwolle field, pass through a similar thickness of beds belonging to this group. Notice has already been taken of the abundant occurrence of *Ostrea thirsae* at Marthaville, the characteristic fossil of the Nanafalia formation, the basal member of the group in Alabama. We must therefore conclude that the Sabine group includes not only the Alabama formations, but at least 1,300 feet of older beds, not represented in the Alabama section.

In view of the completeness of the section presented by the Sabine group along Sabine River, the recent act of the United States Geological Survey in extending the Indio formation of south Texas so as to include the entire exposure of this group on the Texas side of the Sabine uplift, as represented on the "Preliminary Edition of the Geologic Map of Texas," 1932, is most unfortunate. It not only ignores the stratigraphic work of Veatch, Deussen, and other members of the Survey, the paleontologic work of Harris, Vaughan, and others, but extends the original content of the Indio so as to make it practically synonymous with the Sabine group. It is therefore hoped that

[1] C. L. Moody, "Tertiary History of Region of Sabine Uplift, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 5 (May, 1931), pp. 531–51, maps.

[2] H. V. Howe, " 'The Many Salt Dome,' Sabine Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (January–February, 1925), p. 170.

the final edition of this map will not see the formational name Indio[1] used in this sense, for, as a group name, it lacks priority; its type section with a thickness not exceeding 700 feet is only sparingly fossiliferous and represents only a small part of the 3,000-foot Sabine section.

The writer has thought it desirable to list by means of a footnote[2] some of the more important papers dealing with the paleontology and paleobotany of the Sabine group.

CLAIBORNE GROUP

Almost as many names have been applied to subdivisions of this group in Louisiana as to all the remainder of the Tertiary column combined. This situation is primarily due to the rapid change in the position of the shore line of the Claiborne sea in this portion of the Gulf Coast. In the matter of Claiborne formational nomenclature the writer is glad to endorse the excellent work of Moody,[3] whose scholarly treatise on the Sabine uplift contains a particularly clear discussion. In Louisiana the Claiborne is divisible into four formations which will be discussed in order.

CANE RIVER FORMATION

The basal marine formation of the Claiborne group in Louisiana was first recognized to be paleontologically distinct by Vaughan.[4] It

[1] Named by A. C. Trowbridge, "A Geologic Reconnaissance in the Gulf Coastal Plain of Texas Near the Rio Grande," *U. S. Geol. Survey Prof. Paper 131* (1923), pp. 89–91.

[2] *Foraminifera.*—(1) J. A. Cushman and G. M. Ponton, "An Eocene Foraminiferal Fauna of Wilcox Age from Alabama," *Cont. Cush. Lab. Foram. Res.*, Vol. 8, Pt. 3, No. 122 (1932), pp. 51–72, pls. 7–9.

Bryozoa.—(1) F. Canu and R. S. Bassler, *U. S. Nat. Mus. Bull. 106* (1920).

Corals.—(1) T. W. Vaughan, *U. S. Geol. Survey, Monogr. 39* (1900).

Mollusca.—(1) G. D. Harris, "The Lignitic Stage," Pt. I, *Bull. Amer. Paleont.*, No. 9 (1897), 102 pp.; Pt. II, *Bull. Amer. Paleont.*, No. 11 (1899), 128 pp.; "The Cretaceous and Lower Eocene Faunas of Louisiana," *Louisiana Geol. Survey Rept. 1899, Special Rept. No. 6*, pp. 289–310.

(2) J. A. Gardner, "New Species of Mollusca from the Eocene Deposits of Southwestern Texas," *U. S. Geol. Survey Prof. Paper 131* (1923), pp. 109–15, 5 pls.; "Fossiliferous Marine Wilcox in Texas," *Amer. Jour. Sci.*, 5th ser., Vol. 7 (1924), pp. 141–45.

Paleobotany.—(1) E. W. Berry, *U. S. Geol. Survey Prof. Paper 91* (1916); *Prof. Paper 125-A* (1919); *Prof. Paper 131-A* (1922); *Prof. Paper 132-E* (1924); *Prof. Paper 156* (1930).

(2) A. C. Hollick, *Louisiana Geol. Survey Rept. 1899, Special Rept. No. 5*, pp. 276–88.

[3] C. L. Moody, *op. cit.*

[4] T. W. Vaughan, "The Eocene and Lower Oligocene Coral Faunas of the United States," *U. S. Geol. Survey Monogr. 39* (1900).

was later named by Spooner[1] the Cane River beds. His description is quoted as follows.

> In the Cane River are included the 75–150 feet of beds above the Wilcox (Sabine) formation and below the massive Sparta sand. The name Cane River, from the excellent exposures on Cane River at Natchitoches, Louisiana, was suggested by H. V. Howe.
>
> These beds outcrop in a narrow belt trending northeast across southern Sabine and Natchitoches parishes. A few miles east of Red River the strike changes to northwest, and continues in that direction to the Arkansas line. The width of the outcrop is 3–7 miles.
>
> An erosional unconformity separates the Cane River and Wilcox (Sabine) beds. The basal member consists of glauconitic sand and sandy clay, but in some places marine tuff is present at the base. Glauconitic clays predominate in the southern portion of the outcrop, but northward from Bienville Parish they become sandier, until, in northern Bossier Parish they are represented entirely by sands, in part glauconitic, and containing a meager representation of the prolific fauna found farther south. . . .
>
> The Cane River beds, as shown in records of wells drilled east and southeast of the outcrop, are made up chiefly of glauconitic clays with subordinate beds of sand. The thickness increases slightly in the eastern and southeastern parts of the salt-dome region.

In a subsequent paper, Shearer[2] subdivided the Cane River formation into two members, the Cane River clay above and Cane River marl below. These members he described as follows.

> The top of the upper member is sandy shale, which grades downward into smooth, plastic, slightly calcareous clay-shale. This material is characterized by its dark chocolate-brown color, generally specked and streaked with light green. It is all marine, and *Foraminifera* are plentiful.
>
> The lower member consists of fossiliferous, sandy, highly glauconitic marl or soft limestone. It is commonly logged as "salt and pepper sand" because of the appearance of the white limestone with grains of dark glauconite.

He gives the thickness of the Cane River in Catahoula Parish as 333 feet in The Texas Company's Tensas Delta No. B-1 in the northwestern part of the parish, and shows the formation thickening toward the southeast to more than 500 feet.

In the region of the Richland gas field, Gordon[3] indicates that the thickness of the Cane River varies from 215 feet to 360 feet.

The term Mount Selman has been used as a sub-group name by

[1] W. C. Spooner, "Interior Salt Domes of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 3 (March, 1926), pp. 235–36.

[2] H. K. Shearer, *op. cit.*, p. 441.

[3] D. Gordon, *op. cit.*, p. 943.

Wendlandt and Knebel[1] for the Claiborne beds of East Texas which are older than the Sparta sand. This group they divided in descending order into the Weches, Queen City, Reklaw, and Carrizo[2] formations.

In a companion paper, Miss Ellisor[3] restricts the term Cane River to the glauconitic, sandy marl and a glauconitic, clayey sand which appear to correspond to the Cane River marl of Shearer,[4] and uses the name Reklaw for the upper portion of the Cane River which Shearer called the Cane River clay. In the later papers by Moody[5] and Gordon[6] these subdivisions of the Cane River have not been adopted for Louisiana."

SPARTA SAND

The name "Sparta sand" was first used by Vaughan.[7] It was redescribed by Spooner;[8] limited by the Cane River formation below and by the beds designated in the present report as the Cook Mountain formation above. Spooner's description is quoted.

The Sparta sand, owing to the steep dips along the Angelina-Caldwell flexure, outcrops in a narrow belt from Sabine River to the northern end of Saline Lake. From this point northward to the vicinity of Minden it has a width of 10–15 miles.

The lower half of the Sparta sand is made up chiefly of massive sand with interbedded subordinate members of laminated sandy clay. The massive sands are made up of quartz grains somewhat coarser than found in the Wilcox formation. The upper half contains a relatively greater amount of clay than the lower half. Massive sands alternate with beds of finely laminated sandy clay, in part lignitic and in many places containing fossil leaves. The upper 50 feet of beds contain a considerable amount of lignitic material and some thin beds which are particularly well exposed in the vicinity of the town

[1] E. A. Wendlandt and M. Knebel, "Lower Claiborne of East Texas with special Reference to Mount Sylvan Dome and Salt Movements," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1347–75.

[2] The type section of the Carrizo was described by J. Owen, *Texas Geol. and Min. Surv. First Rept. Progress* (1888), pp. 70–74, from Carrizo Springs in Dimmit County, Texas. For a lengthy review of the literature dealing with the correlation of the Carrizo, see: A. C. Trowbridge, *U. S. Geol. Survey Bull. 837* (1932), pp. 52–65. In this paper the Carrizo is placed in the Wilcox (Sabine) below the Bigford formation, which in turn carries a flora reported by Berry (*ibid.* p. 71–72) to be Wilcox (Sabine) and distinctly older than Mt. Selman.

[3] A. C. Ellisor, "Correlation of the Claiborne of East Texas with the Claiborne of Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 10 (October, 1929), pp. 1335–46.

[4] H. K. Shearer, *op. cit.*, p. 441.

[5] C. L. Moody, *op. cit.*

[6] D. Gordon, *op. cit.*

[7] T. W. Vaughan, "A Brief Contribution to the Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1896), p. 25.

[8] W. C. Spooner, *op. cit.*, p. 236.

of Bienville. The beds are commonly light colored, but, depending upon the amount of iron and carbonaceous matter, red- and brown-colored beds occur. Fossils are generally absent from the Sparta sand, but a few species of near-shore forms are found near the middle of the formation. The Sparta sand has a thickness of 400–500 feet, with the greater thickness in the northern part of the salt-dome region.

The Sparta sand was mapped across East Texas by Wendlandt and Knebel,[1] and Miss Ellisor[2] has given several sections from Louisiana into Texas which show the formation to be thinning toward the west. However, Shearer[3] has shown that the formation thickens down dip southeast from the outcrop and reaches a thickness of 600 feet in wells drilled in Catahoula Parish, and farther north Gordon[4] records a thickness in the region of the Richland gas field which ranges from 460 feet to 600 feet, averaging 575 feet in the producing field.

COOK MOUNTAIN FORMATION[5]

The name Cook Mountain has been in use for the past 40 years to indicate the marine beds of the Claiborne lying above the Sparta sand and below the Cockfield (formerly called Yegua in Texas). It was used in this sense for Louisiana by Moody[6] and the present writer agrees with this use. The name St. Maurice which Spooner[7] restricted to these beds had originally been used by Harris[8] to include all of the Claiborne below the Cockfield. It was of later origin than the well established name Cook Mountain and hence should be discarded. Spooner's description of these beds is quoted, with the name Cook Mountain substituted for St. Maurice, and the name Cockfield substituted for Yegua.

The (Cook Mountain) beds, like the Cane River and Sparta sand, outcrop in a narrow belt across Sabine, Natchitoches, and Winn parishes. The outcrop gradually increases in width from Winnfield northward to Ruston on the Vicksburg, Shreveport & Pacific Railroad. The area north of the railroad, to the vicinity of the Arkansas line and eastward to the Ouachita River valley,

[1] E. A. Wendlandt and M. Knebel, *op. cit.*

[2] A. C. Ellisor, *op. cit.*

[3] H. K. Shearer, *op. cit.*, p. 441.

[4] D. Gordon, *op. cit.*, p. 943.

[5] Named by William Kennedy, "A Section from Terrell, Kaufman County, to Sabine Pass on the Gulf of Mexico," *Texas Geol. Survey 3rd Ann. Rept. 1891* (1892), pp. 54–57, after Cook Mountain, in Houston County.

[6] C. L. Moody, *op. cit.*, p. 537.

[7] W. C. Spooner, *op. cit.*, p. 237.

[8] G. D. Harris, "The St. Maurice and Claiborne Stages," *Bull. Amer. Paleont.*, Vol. 6, No. 31 (1919).

is chiefly (Cook Mountain), although many remnants of the (Cockfield) formation are present. This portion of northern Louisiana has not been mapped in enough detail to show the distribution of the (Cook Mountain) and (Cockfield) formations.

The (Cook Mountain) is made up of alternating beds of sands and clays. The sands predominate; they commonly range in color from light gray to red, but in some places are brown, owing to the carbonaceous matter they contain. In structure they are massive, cross-bedded, and laminated. They contain considerably more ferruginous sandstone than is present in the underlying Sparta sands. The clays are gray, green, red, and brown in color, depending upon the iron, glauconite, or carbonaceous content of the individual beds. The glauconitic beds are usually massive, but the sandier clays and the lignitic clays are often laminated. The basal and the upper beds are fossiliferous, and at least one other fossiliferous horizon occurs between the two horizons mentioned. The more perfect fossil shells and corals are found in the glauconitic clays and sands, but an abundance of fossil casts occur in the ferruginous concretions and in the thin ferruginous sandstone beds. The thickness of the (Cook Mountain) beds ranges from 100 to 150 feet.

The name "Minden" was suggested by the present writer during a course of lectures which he was giving in Shreveport a few years ago under the sponsorship of the Shreveport Geological Society. At that time it was not known just how the Cook Mountain of Texas fitted into the Louisiana section. As a result the name came into fairly common use by petroleum geologists and has crept into the literature several times without ever having been formally described. It was mentioned in parentheses by Campbell and Miller[1] and has been attributed to them by later authors. Portions of the writer's office map of the geology of Louisiana, on which the name Minden appeared, were copied by Whittemore[2] without the writer's knowledge during his absence on summer vacation. Acknowledgment was given in the later two publications, but the writer never sanctioned the placing of this name in print. This name has recently spread into the Mississippi literature in a paper by Monroe[3] on the Jackson gas field.

Another name for this formation which has appeared in recent years is "Mount Lebanon." Shearer,[4] who first used the name Mount Lebanon, suggested at the time that Cook Mountain was the proper

[1] I. Campbell and A. D. Miller, "Nepheline Basalt in Richland Parish Gas Field, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 10 (October, 1928), p. 990.

[2] J. W. Whittemore, "The Clays of Louisiana (Shreveport Area)," *Louisiana State Dept. Conservation, Bull. 14* (1927), p. 9.
"The Clays of Louisiana (Monroe-Ruston Area)," *ibid., Bull. 16* (1928), p. 8.
"The Clays of Louisiana (Alexandria Area)," *ibid., Bull. 19* (1929), p. 6.

[3] W. H. Monroe, "The Jackson Gas Field, Hinds and Rankin Counties, Mississippi," *U. S. Geol. Survey Bull. 831* (1932), p. 5.

[4] H. K. Shearer, *op. cit.*, pp. 439–40.

name if subsequent work indicated that the exposure at Cook Mountain proved to be definitely on the same formation.

The only attempt to subdivide the Cook Mountain appeared in a paper by Miss Ellisor.[1] She divided the formation into three members in descending order, named: Saline Bayou,[2] Milams,[3] and Crockett.[4] She indicated that the "Minden" locality corresponded to the Crockett in stratigraphic position.[5]

The names "*Upper*" and "*Lower Saline Bayou* formations" appeared in a paper[6] attributed to the Humble Oil and Refining Company's geological department in 1931. The names suggest that these are two formations having their type localities on Saline Bayou. However, no mention was made of their cropping out in Louisiana, and the statement is made that they

> are not known on the surface in Texas except on its eastern edge, but in deep wells on the coast they consist of brown fossiliferous clays with some sands.

The thickness of these "formations" in the Humble field is given as "Upper Saline Bayou": 972 feet; "Lower Saline Bayou": 537 feet (plus). Inasmuch as these "formations" are not described with a type section ascribed to each, and as no discussion is given as to their relationship to the type section of the former "Saline Bayou member," the present writer feels that they should not be made a further part of Louisiana stratigraphic nomenclature.

COCKFIELD FORMATION[7]

Vaughan's original definition of this formation is quoted as follows.

[1] A. C. Ellisor, *op. cit.*, p. 1339.

[2] The type locality is the same spot as that of the St. Maurice of Harris, namely the bank of Saline Bayou, immediately north of the railroad station of St. Maurice, Winn Parish, Louisiana.

[3] "The type locality of the Milams is in the northeast quarter of Sec. 17, T. 13, R. 3 W., Winn Parish, Louisiana."

[4] The type locality of the Crockett is "in the vicinity of Crockett, Houston County, Texas."

[5] *Op. cit.*, p. 1341.

[6] "The Geology of the Gulf Coast Area of Texas and Louisiana," *Nat. Oil Scouts Assoc. Year Book 1931*, pp. 43, 45.

[7] Originally named Cocksfield Ferry beds by T. W. Vaughan, *Amer. Geol.*, Vol. 15 (1895), p. 220. Concerning the original spelling of the name, A. C. Veatch, *Louisiana Geol. Survey Bull. 4* (1905), p. 32, states: "This name was spelled by Vaughan 'Cocksfield Ferry.' The maps of the Red River Survey (M.S. sheet No. 37, Red River Survey, U. S. Eng'rs., 1889–1890, scale 1:10,000) gave two plantations at the point belonging to 'A. P. Cockfield' and 'W. J. Cockfield.' The ferry name should naturally be spelled in the same way as the name of the owners. The section at 'Cocksfield Ferry,' published by Vaughan . . . is really a section of Petite Ecore, or, as it has been improperly anglicized, 'Petite Ecore Bluff.'"

Conformably above the fossiliferous Lower Claiborne at St. Maurice . . . are laminated non-fossiliferous clays or laminated sand and clay, dipping slightly south. These beds present different lithological phases, sometimes containing more clay and little or no sand.

The same beds are well exposed at Cocksfield Ferry, about halfway between St. Maurice and Montgomery. . . .

At Montgomery, immediately below the Jackson, beds lithologically like those found in the upper part of the St. Maurice section and like those at Cocksfield Ferry are found.

For these beds between St. Maurice and Montgomery, coming between the Lower Claiborne and the Jackson, I propose the local name of *Cocksfield Ferry beds.*

The Cockfield has been redescribed by a number of subsequent workers. Spooner used the name Yegua for this formation, but his limits were the same as for Vaughan's. By substituting the name Cockfield for Yegua, Spooner[2] says:

The (Cockfield) formation outcrops in a narrow belt across southern Sabine Parish. Beginning in the southeast corner of Winn Parish, the outcrop gradually increases in width to the east and north. In the vicinity of Winnfield the strike changes to north, and these beds are exposed in a wide belt as far as the Vicksburg, Shreveport & Pacific Railroad. Their eastern extension is limited by the Ouachita River valley.

The (Cockfield) formation is predominantly sandy; massive light-colored sands alternate with laminated and thin-bedded sandy clays and lignitic clay. The beds are generally light colored, but often red and brown. The maximum thickness of the Cockfield does not exceed 500 feet. Fossil leaves are present in the lignitic clays in many places, but marine fossils are not found in the formation.

In discussing the Cockfield of Catahoula Parish, Shearer[3] states:

The top of the Cockfield, or contact with the Jackson, is generally well marked by a change from greenish shale to gray or lignitic sand and shale. . . .

The lower contact of the Cockfield is obscure, because of gradation downward into the Mount Lebanon (Cook Mountain) formation.

Miss Ellisor[3] also adds:

Seaward from the outcrop the Cockfield member becomes marine in character.

PALEONTOLOGY OF CLAIBORNE GROUP

Numerous monographs have appeared during the past hundred years dealing with the paleontology of the Claiborne group. The famous Gosport sand locality at Claiborne Bluff in Alabama has, how-

[1] W. C. Spooner, *op. cit.*, p. 238.

[2] H. K. Shearer, *op. cit.*, p. 438.

[3] A. C. Ellisor, *op. cit.*, p. 1339.

ever, supplied the greater number of the fossils. The exact stratigraphic position of many species described from localities in the Claiborne older than the Gosport sand has not been given in connection with all descriptions. As a means of aiding stratigraphers working in Louisiana the following extensive papers describing Claiborne fossils are listed:

1. Isaac Lea, "Contributions to Geology (Tertiary of Alabama)" (Phila., 1833). 227 pp. Gives pictures and descriptions of over 200 fossils from Claiborne Bluff, Alabama.

2. T. A. Conrad, "Fossil Shells of the Tertiary Formations of North America . . . ." (Phila., 1832–1835); republished by G. D. Harris (Washington, 1893). Describes and figures a very large number of Claiborne fossil mollusca.

3. Antoine de Gregorio, "Monographie de la faune éocénique de l'Alabama." *An. G. Paleont.* 7–8 (1890). 346 pp., 46 pls. This describes and figures over 600 species of fossils, mostly from the Claiborne sand.

4. M. Cossman, "Notes complementaires sur le faune éocénique de l'Alabama," *An. G. Paleont.*, 12 (1893). 52 pp. A revision of de Gregorio's work with additions.

5. G. D. Harris, "Pelecypoda of the St. Maurice and Claiborne Stages," *Bull. Amer. Paleont.*, Vol. 6 (1919). 268 pp., 59 pls. The most important paper describing the fossil clams of the Claiborne of Louisiana. Divides what is now referred to the Claiborne group into two groups or "Stages"; restricting the Claiborne "Stage" to the "upper Claiborne"—Gosport sand, Cockfield, "Yegua" equivalents, and calling the portion of the Claiborne which he previously had designated "lower Claiborne" the St. Maurice stage. This "Stage" included the formations of the Claiborne group discussed in this report that lie below the Cockfield formation.

6. T. W. Vaughan, "The Eocene and Lower Oligocene Coral Faunas of the United States," *U. S. Geol. Survey Monogr. 39* (1900). 263 pp. Describes many fossil corals from the Claiborne group of Louisiana.

7. Clark and Twitchell, *op. cit.* Principal reference for Claiborne Echinodermata.

8. F. Canu and R. S. Bassler, "North American Early Tertiary Bryozoa," *U. S. Nat. Mus. Bull. 106* (1920). 879 pp., 279 figs., 162 pls. A monumental treatise which, while not describing *Bryozoa* from Louisiana Claiborne localities, contains the pictures and descriptions of many species which are common in the Louisiana formations.

9. There are no monographic papers on Claiborne foraminifera. However, micropaleontologists may obtain assistance from papers by Cushman and Thomas in *Jour. Paleont.*, Vol. 3, No. 2, pp. 176–184; and Vol. 4, No. 1, pp. 33–41; and from a paper by Weinzierl and Applin, also in *Jour. Paleont.*, Vol. 3, No. 4, pp. 384–410.

10. E. W. Berry, "The Middle and Upper Eocene Floras of Southeastern North America," *U. S. Geol. Survey Prof. Paper 92* (1924). While the stratigraphic terminology used in this comprehensive paper is no longer customary and is likely to be confusing, it contains the pictures and descriptions of two fossil plants from 1½ miles N.E. of Bienville in Bienville Parish—a spot which lies in the area of the Sparta sand, and also the pictures and descriptions of a large number of fossil plants from Columbia, in Caldwell Parish—a spot which lies in the outcrop of the Cockfield.

JACKSON GROUP[1]

The writer has recently been studying the stratigraphy of the Jackson group and his examination of a literature comprising several hundred titles dealing with the group has disclosed that more than 75 names have been applied to it, or to subdivisions of it. The Louisiana literature, however, is fortunately not complicated by the introduc-

[1] Originally described and named for Jackson, Mississippi, by T. A. Conrad, "Observations on the Eocene Deposit of Jackson, Miss., with Descriptions of Thirty-Four New Species of Shells and Corals," *Proc. Acad. Nat. Sci. Phila.*, Vol. 7 (1855), pp. 257–63.

tion of many of these terms; in fact only the name Fayette[1] has appeared as a formational subdivision. It has not been used by subsequent authors.

The Jackson group of Louisiana has been briefly described during the past 40 years in papers by Vaughan,[2,3] Harris and Veatch,[4] Harris,[5] Veatch,[6,7,8] Shearer,[9] and Howe and Wallace.[10]

From the latter publication the following description is quoted.

> The Jackson is the most fossiliferous formation exposed at the surface in Louisiana. . . . it was demonstrated by Veatch thirty years ago that the bluffs on the western bank of the Ouachita River in Louisiana afforded by far the best known section of the formation. These exposures are among the most prolific upper Eocene fossil collecting localities in the world, and it was by means of fossils collected from these bluffs that the Eocene was first definitely recognized in Louisiana some 98 years ago. These bluffs have also furnished the type specimens of "*Basilosaurus*" or *Zeuglodon cetoides*, a remarkable whale-like cetacean that inhabited the upper Eocene waters of the Gulf-coastal region, as well as the type specimens of several other noted fossils. . . .
>
> The Jackson formation is known to extend along the Ouachita River from Stock Landing in Caldwell Parish to Carter Landing in Catahoula Parish. . . .
>
> From its exposures along the western bank of the Ouachita, the Jackson extends southwest as a narrow band across portions of Caldwell, Catahoula, LaSalle, Winn and Grant Parishes to the region of Montgomery on the Red River and thence crosses Natchitoches Parish to the region lying north of Bayou Toro in Sabine Parish. . . .

[1] Introduced into Louisiana stratigraphic terminology to designate the sands at the top of the Jackson in the region west of the Red River by G. C. Matson, "The Catahoula Sandstone," *U. S. Geol. Survey Prof. Paper 98* (1916), p. 224.

[2] T. W. Vaughan, "The Stratigraphy of Northwestern Louisiana," *Amer. Geol.*, Vol. 15 (1895), pp. 221–23.

[3] *Idem*, "Geology and Paleontology of Northwestern Louisiana," *U. S. Geol. Survey Bull. 142* (1896), pp. 22–24 (also contains lists of Claiborne and Jackson fossils and describes a number of species from the Jackson of Louisiana).

[4] G. D. Harris and A. C. Veatch, "A Preliminary Report on the Geology of Louisiana," *Louisiana Geol. Survey Rept.* (1899), pp. 89–93.

[5] G. D. Harris, "The Geology of the Mississippi Embayment with Special Reference to the State of Louisiana," *Louisiana Geol. Survey Rept.* (1902), pp. 22–25.

[6] A. C. Veatch, "The Geography and Geology of the Sabine River," *Louisiana Geol. Survey Rept.* (1902), pp. 131–32.

[7] *Idem*, "Notes on the Geology along the Ouachita," *Louisiana Geol. Survey Rept.* (1902), pp. 164–67.

[8] *Idem*, "The Underground Waters of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), p. 39; "Geology and Underground Water Resources of Northern Louisiana with Notes on Adjoining Districts," *Louisiana Geol. Survey Rept., 1905, Bull. 4* (1906), pp. 35–36.

[9] H. K. Shearer, "Geology of Catahoula Parish," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), pp. 438–39.

[10] H. V. Howe and W. E. Wallace, "*Foraminifera* of the Jackson Eocene at Danville Landing on the Ouachita, Catahoula Parish, Louisiana," *Louisiana Dept. Conserv. Geol. Bull. No. 2* (1932), pp. 7–17.

For the significant region of Catahoula Parish, Shearer[1] has the following to say of the Jackson.

> The Jackson formation, after allowance is made for the probable thickness of similar Vicksburg beds at the top, ranges from 525 to 575 feet in thickness in all wells in Catahoula Parish. There is no great thickening in any direction within this area, but on the southwest, in Estabrook and Rogers' State No. 1, Sec. 33, T. 6 N., R. 3 E., Rapides Parish, where the Vicksburg is thin or absent, 668 feet of beds are referred to the Jackson formation.
>
> The Jackson consists almost entirely of green clay-shale, more or less calcareous and fossiliferous. In the lower part there are some thin beds or lenses of sand, one of which, about 230 feet above the base of the formation, has produced a few barrels of oil at White Sulphur Springs, LaSalle Parish. . . .

The complicated zonal nomenclature, based on micropaleontology, which has appeared in Texas Jackson literature has scarcely been referred to in papers dealing with the Jackson of Louisiana and will not be entered into in this discussion. However, for the benefit of those stratigraphers not intimately acquainted with the kaleidoscopic changes which have taken place in foraminiferal generic nomenclature, the writer calls attention to the fact that *Discorbis jacksonensis* var. *texana* for which Cushman and Applin[2] named their "*Discorbis* zone" has recently been placed by Cushman and Ellisor[3] in the genus *Anomalina*. Hence the name, if retained, would become "*Anomalina jacksonensis* var. *texana*" zone.

At this point it should be noted that the United States Geological Survey, on their preliminary edition of the Geologic Map of Texas (1932), have shown the entire Jackson outcrop under the name "Fayette sandstone," and have brought this "formation" to the Texas-Louisiana line. This mapping of the Jackson outcrop under the certainly questionable term "Fayette sandstone"[4] not only is damaging to the name Jackson, one of the best defined groups of the Tertiary, but overlooks the work of Dumble, Deussen, Veatch, and others who have shown the Jackson of east Texas to consist in large part of marine clays, and obscures a great deal of interesting geologic history. It

[1] H. K. Shearer, *op. cit.*, p. 438.

[2] J. A. Cushman and E. R. Applin, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 2 (February, 1926), pp. 157–58.

[3] J. A. Cushman and A. E. Ellisor, "Some New Tertiary Foraminifera from Texas," *Cont. Cush. Lab. Foram. Res.*, Vol. 7, Pt. 3, No. 107 (1931), p. 58.

[4] Originally used by R. A. F. Penrose, Jr., *Texas Geol. Survey First Ann. Rept.* (1890), p. 47, "as a name for all the Tertiary beds on the Brazos and Colorado rivers and the Rio Grande lying stratigraphically above the 'Marine beds' (now known as Cook Mountain formation)." For history of nomenclature of Fayette, see A. C. Trowbridge, *U. S. Geol. Survey Bull. 837* (1932), pp. 141–42.

is ardently to be hoped that on the final edition of this map the "Fayette sandstone," which has heretofore been used as a formation name, will not be used as a substitute for the Jackson group.

Few references have been made to the Jackson in the region south of its outcrop, and these mostly in the salt-dome literature. In the paper attributed to the Humble Oil and Refining Company's geological department[1] it was observed that:

> Until a few years ago, what is now termed Lower Oligocene (meaning Vicksburg) was referred to as the upper part of the Jackson. Hence in many older (meaning before 1931) paleontological reports the term Jackson may refer to Lower Oligocene beds. Also, care should be taken to avoid confusing the present known Lower Oligocene (Vicksburg) with the Marginulina or lowest zone, of the Middle Oligocene, to which, a few years ago, paleontologists referred as the Lower Oligocene.

It is, however, well known that the Jackson thickens rapidly from its outcrop gulfward in Texas and it is only reasonable to assume a similar condition to exist in Louisiana. From the foregoing, it should not be concluded that the Jackson does not occur on the coastal domes within present drilling reach. Despite the fact that Jackson has not been reported from the Anse la Butte dome in previous literature,[2] the writer possesses a core from one of the wells belonging to the Ayers Brothers (depth 1500 feet) which contains abundant specimens of *Discorbis hemisphaerica* and *Discorbis globulospinosa*, species which the writer has used for a number of years as markers of the lower portion of the Jackson. The latter species has just been described in a paper by Cushman[3] entitled "New Foraminifera from the Upper Jackson Eocene of the Southeastern Coastal Plain Region of the United States." His specimen came from Jackson, Mississippi, and the species occurs there in great abundance in the typical Moody's Branch marl—which is the formation lying at the *base* of the type section of the Jackson group. Both of these species occur in abundance at Gibson Landing on the Ouachita, Louisiana, in a similar stratigraphic position.

For the benefit of stratigraphers desiring to use Jackson fossils, the following papers are enumerated.

[1] "The Geology of the Gulf Coast Area of Texas and Louisiana," *Nat. Oil Scouts Assoc. Year Book 1931*, p. 42.

[2] D. C. Barton, "Petroleum Potentialities of Gulf Coast Petroleum Province of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 11 (November, 1930), p. 1387.

Nat. Oil Scouts Assoc. 1931 Year Book, pp. 45–47.

[3] J. A. Cushman, *Cont. Cush. Lab. Foram. Res.*, Vol. 9, Pt. 1, No. 127 (1933), p. 15, pl. 2, figs. 5a–c.

Foraminifera

1. J. A. Cushman and E. R. Applin, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 2 (February, 1926), pp. 154–89.

2. Papers appearing in *Cont. Cush. Lab. Foram. Res.*, Vol. 1, Pt. 3 (1925), pp. 65–70; Vol. 2, No. 2 (1926), pp. 29–38; Vol. 4, Pt. 3 (1928), pp. 73–79; Vol. 7, Pt. 3 (1931), pp. 51–59; Vol. 8, Pt. 2 (1932), pp. 40–42; Vol. 9, Pt. 1 (1933), pp. 1–21.

3. H. V. Howe and W. E. Wallace, *Louisiana Dept. Conserv. Geol. Bull. No. 2* (1932). 118 pp., 15 pls.

Bryozoa

1. F. Canu and R. S. Bassler, "North American Early Tertiary Bryozoa," *U. S. Nat. Mus. Bull. 106* (1920). 879 pp., 279 figs., 162 pls. This tremendous document describes 432 species of fossil bryozoa from the Jackson of the Gulf Coast. Of these 346 are confined to the Jackson; 19 extend from the Claiborne into the Jackson; 44 extend from the Jackson into the Vicksburg; and 3 extend from the Claiborne through the Jackson into the Vicksburg. This paper can be of great use to stratigraphers in definitely placing the position in the Jackson of many noted fossil localities. None of the bryozoa are described from Louisiana localities. Bryozoa are, however, relatively common in the Louisiana Jackson, and this paper should be very helpful in accurately placing the stratigraphic position of the localities at which they occur.

Corals

1. T. W. Vaughan, *U. S. Geol. Survey Monogr. 39* (1900).

Echinodermata

1. W. B. Clark and M. W. Twitchell, *U. S. Geol. Survey Monogr. 54* (1915).

Mollusca

Descriptions scattered through too many small papers to enumerate. The most important is by T. A. Conrad, *Acad. Nat. Sci. Phila. Proc.*, Vol. 7 (1855), pp. 257–263; illustrated in B. L. C. Wailes, "Report on the Agriculture and Geology of Mississippi" (Jackson, Miss., 1854). 371 pp.

Plants

1. E. W. Berry, "The Middle and Upper Eocene Floras of Southeastern North America," *U. S. Geol. Survey Prof. Paper 92* (1924). Lists fossil plants from 5 localities referred to the Jackson in Louisiana, several of which lie in the Catahoula outcrop.

2. O. M. Ball, "A Contribution to the Paleontology of the Eocene of Texas," *Texas A. & M. Coll. Bull.*, Ser. 4, Vol. 2, No. 5 (1931). 173 pp., 48 pls. In this paper Ball questions the type locality of the Catahoula and refers species of plants described from there by Berry to the "Jackson formation."

Oligocene Period

Vicksburg group[1]

The small outcrop of the Vicksburg group in the northwestern part of Catahoula Parish attracted a good deal of attention in the early geologic literature of Louisiana.[2] The following description of Vicksburg distribution in Louisiana is taken from Harris.[3]

[1] Named for Vicksburg, Mississippi, by T. A. Conrad, *Proc. Phila. Acad. Nat. Sci.*, Vol. 3 (1846), pp. 280–81. For an historical discussion of the term "Vicksburg" see C. W. Cooke, *U. S. Geol. Survey Prof. Paper 129* (1922), pp. 79–85; and for an analysis of the correlation of the formations belonging to the Vicksburg group see C. W. Cooke, *Jour. Wash. Acad. Sci.*, Vol. 8 (1918), pp. 186–98.

[2] E. W. Hilgard, *Amer. Jour. Sci.* (2), Vol. 48 (1869), pp. 339–40; "Supplemental and Final Report of a Geological Reconnaissance of Louisiana . . . , New Orleans, 1873," p. 33; *Amer. Jour. Sci.* (3), Vol. 30 (1885), p. 269.

T. W. Vaughan, *Amer. Geol.*, Vol. 15 (1895), p. 223; *U. S. Geol. Survey Bull. 142* (1896), pp. 22–24, 52.

G. D. Harris and A. C. Veatch, *Louisiana Geol. Survey Rept. 1899*, pp. 93–94.

[3] G. D. Harris, *Louisiana Geol. Survey Rept. 1902*, pp. 26–27.

The Vicksburg beds of Louisiana are confined to the region about Rosefield P.O., or more definitely, from a point about ½ mile west of Enterprise P.O. on the Ouachita, to perhaps 5 miles southwest of Rosefield. Just south of Rosefield the hills are capped by Grand Gulf (Catahoula) material, but the steep and deep valleys on all sides show Vicksburg marls, limestone boulders, and often Vicksburg fossils. Some locations have been already specified in our Report of 1899. Heretofore, however, the Vicksburg fossils of Louisiana have come apparently from one and the same horizon. Bluish or yellowish marls, with light colored limestone boulders of various size usually indicate the propinquity of good collecting grounds. Now we are able to state that there are at least two fossil-bearing horizons between 40 and 50 feet apart. They are both seen in the vicinity of Sone's store southeast of Rosefield P.O. In a hollow south of his house about ⅓ mile, there is a seam of bluish clay literally packed with small bivalve shells of one species, viz: *Corbula alta* Con. The usual Vicksburg fossiliferous bed is seen a few yards southeast of the same house, in narrow, deep, storm-carved channels. In several places hereabouts a seam of "coal" is found, occupying a stratigraphic position about equivalent to the *Corbula* bed, though presumably just a little below it as is seen below in the Vicksburg section. To the southwest of Rosefield, some four or five miles, fossils are reported in the deep ravines that occur just below the Grand Gulf sandstone horizon.

A recently constructed logging road which passes by the post-office of Rosefield has afforded a number of cuts which greatly facilitate the study of the Vicksburg section. Harris was correct in noting the presence of two fossil zones. The upper zone, some 20 feet in thickness, is well exposed in a large cut beneath the highway under-pass a short distance south of Sone's store. The beds here are clays, banded with glauconite and with one very pronounced shell layer or coquina perhaps 2 feet in thickness. These beds carry *Arca lesueri*, *Pecten poulsoni*, and a large Byram marl fauna. Below these clays 5–10 feet of section is covered. The second fossiliferous zone is then exposed in a cut about ¼ mile northeast of the under-pass and consists of several feet of concretionary limestone or marl which may be correlated with the limestone in the type section at Vicksburg. Below this limestone the Vicksburg consists of 20 or more feet of sandy clays with a soft unconsolidated bed of yellowish sand several feet thick at the base which contains a few shell fragments and is evidently marine. It rests with an irregular contact on fine clays carrying brown plant impressions. There is nothing present in this section which suggests the presence of any marine horizon similar in age to the Red Bluff of Mississippi. The first typical heavy sands of the Catahoula are exposed in a cut about ½ mile southwest of Rosefield.

In describing the thickness of the Vicksburg in Catahoula Parish, Shearer[1] says:

[1] H. K. Shearer, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14, No. 4 (April, 1930), p. 437

The thickness included as "Vicksburg and Jackson" in the accompanying correlations is measured from the top of the Vicksburg marl to the base of the Jackson formation. This does not include all of the Vicksburg, as there is a thin layer of that formation above the marl. In The Texas Company's Harris-Hyman No. 1, Vicksburg fossils were recognized 50 feet above the lime or marl; and in the Standard Oil Company's Tensas Delta No. 1, there is 40 feet of gumbo and gummy shale, probably belonging to the Vicksburg, above the marl. In this Standard well there is about 100 feet of sandy formation, which may be considered lower Vicksburg, below the marl, as the first Jackson fossils recognized were 108 feet below the top of the marl. In the Texas well the first definite Jackson was found 106 feet below the top of the marl. It is safe, therefore, to state that the total thickness of the Vicksburg is 150 feet in the Standard Oil Company's Tensas Delta No. 1, and increases only slightly toward the east.

There is little reliable published information concerning the Vicksburg group in the salt dome region of south Louisiana. A recent paper by the Humble Oil and Refining Company's geological department[1] mentions "Lower Oligocene" (presumably Vicksburg) "in flanking wells at Starks, Vinton, Hackberry, Bayou Bouillon and Jennings." The same paper (p. 39) gives a figure of 1500 feet for the thickness of the Vicksburg group in the salt dome region. This figure is probably derived from wells on the Texas coastal domes, but it should be fully as great if not greater in coastal Louisiana. However, accurate figures are not available for the salt-dome region because the great thickness of the Miocene and younger sediments has buried the Vicksburg group so deeply that wells "off-structure" have not been drilled deep enough to pass through the full section. It is probable that the top of the Vicksburg lies at a depth of between 8,000 feet and 10,000 feet in the region of the salt domes along the "line of the Southern Pacific railroad" and the depth is of course greater to the south of that line.

Important papers dealing with the paleontology of the Vicksburg group are:

Foraminifera

1. J. A. Cushman, *U. S. Geol. Survey Prof. Paper 129* (1922), pp. 87–152, 22 pls.; *U. S. Geol. Survey Prof. Paper 133* (1923), pp. 11–67, 8 pls.; *Cont. Cush. Lab. Foram. Res.*, Vol. 5, Pt. 2, No. 77 (1929), pp. 40–48.

2. J. A. Cushman and A. C. Ellisor, *Cont. Cush. Lab. Foram. Res.*, Vol. 7, Pt. 3, No. 107 (1931), pp. 51–58.

3. H. V. Howe, *Jour. Paleont.*, Vol. 2, No. 1 (1928), pp. 13–14; *Jour. Paleont.*, Vol. 2, No. 3 (1928), pp. 173–176; *Jour. Paleont.*, Vol. 4, No. 3 (1930), pp. 263–67; *Jour. Paleont.*, Vol. 4, No. 4 (1930), pp. 327–31.

Bryozoa

1. R. Canu and R. S. Bassler, *U. S. Nat. Mus. Bull. 106* (1920).

[1] *Nat. Oil Scouts Assoc. Year Book 1931*, p. 45.

Corals

1. T. W. Vaughan, *U. S. Geol. Survey Monogr. 39* (1900).

Echinodermata

1. W. B. Clark and M. W. Twitchell, *U. S. Geol. Survey Monogr. 54* (1915).

Mollusca

1. T. A. Conrad, *Jour. Acad. Nat. Sci. Phila.* (2), Vol. 1 (1848), pp. 111–34; *idem* (1849), pp. 207–09.

Miocene Period

Catahoula formation;[1] Tampa limestone; "*Discorbis, Heterostegina* and *Marginulina* zones" of so-called "Middle Oligocene"

Veatch's original description of the Catahoula formation[2] is quoted.

Overlying the fossiliferous Vicksburg clays and limestones is a series of sandstones and greenish clays which are generally quite different, lithologically, from any of the older beds of the Tertiary series in Louisiana and Arkansas. The sandstones which are the characteristic feature of this formation range in thickness from a few inches to 50 or 60 feet, and thicknesses of as much as 140 feet have been reported. These sand beds are often cemented by silica into very hard quartzites, but such occurrences are essentially local, and the quartzitic beds pass laterally in very short distances into soft sandstones or even unconsolidated sands. These sandstones and quartzitic layers have resisted erosion more than the underlying clays and unconsolidated sands of the Eocene and so have formed a line of rocky hills, the Kisatchie Wold, extending across Louisiana, into Texas on the one hand and into Mississippi on the other.

These beds contain no indications of marine life, but land plants are abundant and fresh-water shells have been found in several places. The change from the conditions existing in the Vicksburg is very marked and indicates an elevation during which the region where the oceanic conditions were favorable for the growth of marine life was considerably south of the present outcrop of the formation.

These beds were observed at Grand Gulf, on Mississippi River, in Claiborne County, Miss., by Wailes, the first State Geologist of Mississippi, who referred to them as the "Grand Gulf sandstones." Later Hilgard used the name "Grand Gulf group" to include the beds exposed in southern Mississippi between the Vicksburg and the relatively recent coastal clays (Port Hudson), and the name has been used with varying shades of meaning by different authors since that time.

In view of this confusion and in order to furnish a name not likely to be misunderstood, the name Catahoula formation is used in this paper as a

[1] First used in place of Grand Gulf by A. C. Veatch, "The Underground Waters of Northern Louisiana and Southern Arkansas," *Louisiana State Expt. Station, Louisiana Geol. Survey Bull. 1* (1905), p. 90.

[2] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), pp. 42–43.

synonym for the "typical Grand Gulf" or the "Grand Gulf proper." This new name is from Catahoula Parish, Louisiana, which is directly across the Mississippi Valley from Grand Gulf and where there are many outcrops which are lithologically and stratigraphically counterparts of the beds of the old type locality. From this place the beds have been traced eastward through Mississippi into Alabama, where they apparently grade into a series of fossiliferous sands and calcareous clays known as the "Chattahoochee group." To the west they extend in a very pronounced line across Louisiana into eastern Texas, and, according to Dumble, are continued across that State in his Oakville beds. The thickness of this formation, as shown by comparative cross sections based on wells at Alexandria and Boyce and on dip observations on Sabine River, is about 1,100 feet.

The most extensive discussion of this formation is contained in a paper by Matson[1] in which he concludes (p. 223) that the Catahoula is interbedded with the Vicksburg, instead of lying unconformably upon it as had been claimed by Harris and Veatch[2] on the authority of Hilgard.[4] He also states (p. 209):

> Investigations made by the author in 1911 showed that the beds at the Catahoula type locality are in part the equivalent of the Chattahoochee formation and in part the equivalent of the Vicksburg limestone. . . .

That the Catahoula was to be correlated with the Chattahoochee had previously been indicated by Miss Maury,[1] who stated:

> The Grand Gulf (Catahoula) sandstones reach their eastern limit in south-central Alabama. Near Oak Grove the typical sandstone beds pass beneath the Oak Grove sand, indicating that the sandstone is approximately of the same age as the Chattahoochee.

In view of the foregoing, Matson concluded that the Catahoula was Oligocene in age and many subsequent writers, particularly those who have dealt with the Texas extension of the formation, have continued to place it in the Oligocene. It should be noted, however, that the Chattahoochee, now called Tampa limestone[5] is referred to the Miocene by both the Geological Survey of the state in which it occurs and by the United States Geological Survey. Moreover, the present writer refers the highest fossiliferous section in the Vicksburg at Rose-

[1] G. C. Matson, "The Catahoula Sandstone," *U. S. Geol. Survey Prof. Paper 98* (1917), pp. 209–26.

[2] G. D. Harris and A. C. Veatch, *Louisiana Geol. Survey Rept. 1899*, Pt. 5, p. 95.

[3] E. W. Hilgard, "The Later Tertiary of the Gulf of Mexico," *Amer. Jour. Sci.*, Vol. 22 (1881), pp. 58–65.

[4] C. J. Maury, "Comparison of the Oligocene of Western Europe and the Southern United States," *Bull. Amer. Paleont.*, Vol. 3, No. 15 (1902), p. 70.

[5] C. W. Cooke and S. Mossom, "Geology of Florida," *Florida Geol. Survey 20th Ann. Rept.* (1928), pp. 78–93.

field to the Byram marl—the top bed of the Vicksburg group. He also objects to the contention of Matson that the sands at the base of the Vicksburg section at Rosefield are similar to the Catahoula, for they are marine and are devoid of siliceous cement. It is his belief that Hilgard was right in stating that the Catahoula lies unconformably upon the Vicksburg, for the outcrop of that formation, which is several miles wide in the region between Enterprise and Rosefield, has entirely disappeared beneath the Catahoula west of Rosefield. A similar unconformity at the base of the Tampa limestone has been noted by Cooke and Mossom;[1] they state:

> In western Florida the Tampa limestone lies unconformably upon the Byram marl or, where that is absent, upon the Glendon limestone. The Glendon has been recognized beneath the Tampa in samples from a well drilled 3 miles east of Woodville, and the unconformable contact of the Glendon and the Tampa is exposed on the Suwannee at Ellaville. So far as is known, nothing intervenes between the Tampa and the Ocala limestones in Citrus, Sumter, and Hernando counties.
>
> The Tampa limestone is generally regarded as the time equivalent of the Catahoula sandstone of the Gulf States, but as this correlation is based chiefly upon the relative stratigraphic positions of the two formations and is not supported by reliable paleontologic evidence, it should be regarded as merely provisional. . . .

The fauna of the Tampa limestone has not been studied in detail. Cooke and Mossom (p. 82) note the common occurrence of *Archais floridanus* (Conrad), a genus of *Foraminifera* found only in tropical waters, and state that siliceous pseudomorphs of shells are common. The abundance of silica which ordinarily cements the outcropping sands of the Catahoula so as to form veritable quartzites perhaps derived from the volcanic ash beds which it contains, is suggestive, but more conclusive is the presence of great amounts of palm wood[2] indicating similar tropical conditions of deposition.

Matson[3] described the lithology of the Catahoula as follows.

> The Catahoula sandstone is composed of many alternations of sandstones, sands, and clays, the arenaceous sediments predominating and the argillaceous materials being distributed in more or less extensive beds of lenticular shape. Loose sands are comparatively rare, and interlamination of sands and clays is not conspicuous. The sandstones are commonly fine-grained, and many of them contain more or less clay. Locally coarse-grained sandstones or fine-grained conglomerates are found, and the material is largely quartz, either in the form of pebbles or sand. In some of the sand the

[1] *Op. cit.*, p. 83.

[2] See the remarks by W. W. Berry, "The Flora of the Catahoula Sandstone," *U. S. Geol. Survey Prof. Paper 98*, p. 28.

[3] G. C. Matson, *op. cit.*, pp. 213, 215.

particles are so minute that the rock resembles clay. An exception to the general character of the conglomerate is found in layers of clay pebbles that have been noted in the sandstones and in the sands resulting from weathering. These clay pebbles and those formed from quartz are commonly distributed in lines parallel to the stratification of the rock, though they are in few places so numerous as to make a definite stratum themselves. In some places masses of clay a few inches in diameter occur in association with pebbles. The occurrence of clay conglomerates is not restricted to any portion of the formation, but the pebbles are scattered from top to bottom and appear to be the result of local conditions of sedimentation rather than to indicate any widespread unconformity.

Cross-bedding is general throughout the formation, and in some places short lenses of sandstone show concentric banding. The beds are as a rule only slightly indurated though in a few places in western Mississippi the rock is sufficiently well cemented to be used for building stone. At Grand Gulf, Miss., near Pollock, La., and at some other localities thin layers are firmly cemented into a very dense quartzite, but rock of this type is apparently of only local occurrence. A change from slightly consolidated sands to quartzite in this formation would scarcely be expected, but it has occurred in some places where the type and quantity of mineral matter in solution in the waters furnished favorable conditions for the deposition of silica in the sands.

The sandstones and sands vary in color from gray to white, with locally a light-greenish tinge. The clays are commonly massive, more rarely interlaminated with sand, and show a tendency toward cuboidal fracture. Many of the clay beds are shown by an ordinary hand lens to contain a very large percentage of fine sand, and in some places this material is noticeable without a lens. In general the clays are somewhat sandy, though some thin beds are notably free from silica. Selenite and probably some of the amorphous forms of gypsum are in places abundant in the clays and occur in a few localities in the sandstones. Here and there rosettes of calcium carbonate occur on the surfaces of the clay layers and in the crevices where the clays are slightly broken or jointed. These rosettes have usually been regarded as accumulations of gypsum, but many of them dissolve with vigorous effervescence when placed in dilute hydrochloric acid, revealing the presence of the carbonate.

The clays of the Catahoula sandstone have a wide range in color, from light gray or white to brown or black. The dark colors are due to the presence of organic matter, either in thin laminae or distributed in the form of particles of lignitized wood. The purer clays are pale blue or green when first exposed to the atmosphere, but on weathering the color changes to gray or white.

A paper entitled "Petrographic Evidence on the Origin of the Catahoula Sandstone of Texas" by Marcus I. Goldman[1] was published in 1915. Unfortunately Goldman gave no localities for his samples though he stated that:

This investigation was made in connection with a paleobotanical study of the Catahoula formation by Professor Edward W. Berry of Johns Hopkins University.

[1] M. I. Goldman, *Amer. Jour. Sci.*, Vol. 39 (1915), pp. 261–87.

He stated on Berry's authority that the flora at this locality contained *Myristica* or nutmeg (fruits) and other plants and that a report by him and G. C. Matson would probably be published later by the United States Geological Survey. Berry[1] described this species the following year and gave the location as a cut on the International and Great Northern Railroad in southern Trinity County, where a spur to the Government lock leaves the main line, assigning it to the Catahoula formation, which he stated "in this area is either late Eocene or early Oligocene in age."

However, in a subsequent paper, Berry[2] states regarding this locality: "Catahoula (?) sandstone (not regarded as Catahoula by me, but older and of Jackson age), . . ."

As Berry did not include this species in his paper on the "Flora of the Catahoula Sandstone"[3] which was a companion paper to the one by Matson on the Catahoula and subsequent to Goldman's, the writer suspects Goldman really dealt with a continental phase of the Jackson Eocene rather than with the Miocene Catahoula.

The writer[4] noted the presence of a small amount of volcanic ash in the Catahoula at the famous Chalk Hills locality in Catahoula Parish 2 miles south of Rosefield, from which place Berry had described a small flora. However, no petrographic study of the type Catahoula has been made to date. Recently the name "Catahoula tuff"[5] has appeared in the Texas literature in a paper by Lahee, who states:

> Briefly, then, the decision has been reached by the U. S. Geological Survey to use "Catahoula tuff" for Bailey's "Gueydan," and to retain "Frio clay" for the formation between the Fayette sandstone below and the Catahoula tuff above. This is in conformity with the San Antonio Committee's recommendation.

The writer considers the name "Catahoula tuff" most unfortunate. The type locality of the Catahoula is in Louisiana several hundred miles east of the type locality of the Gueydan and by no stretch of the imagination may it be considered a "tuff." The addition of the term

[1] E. W. Berry, "A Fossil Nutmeg from the Tertiary of Texas," *Amer. Jour. Sci.*, 4th. ser., Vol. 42 (1916), pp. 241–45, Figs. 1–6.

[2] *Idem*, "The Middle and Upper Eocene Floras of Southeastern North America," *U. S. Geol. Survey Prof. Paper 92* (1924), p. 165.

[3] *Idem*, *U. S. Geol. Survey Prof. Paper 98* (1917), pp. 227–51.

[4] H. V. Howe, "Louisiana's Mineral Resources, Past and Present," *The South's Development, Manufacturer's Record*, Vol. 86, No. 24, Pt. 2 (1924), pp. 378–81.

[5] F. H. Lahee, "Frio Clay, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 1 (January, 1932), pp. 101–02.

"tuff" to the well established stratigraphic unit Catahoula can not fail to be misleading to workers in other regions. Bailey[1] has stated:

> There is a great difference in facies between the Gueydan of southern Texas, as I defined it, and the Catahoula formation at its type locality in Louisiana.

He also indicates that a considerable part of the Gueydan is not a true tuff. If the Gueydan is the exact equivalent of the Catahoula, which may be open to legitimate question in view of the great distance between their type localities, and if there is legitimate reason why the name Gueydan should not be used, which was not stated in Lahee's note, then it would be much less confusing to call it simply Catahoula.

It has already been noted that the stratigraphic workers in the states to the east of Louisiana have concluded that the Catahoula sandstone is a continental deposit more or less contemporaneous with the Chattahoochee, or as it is now called, the Tampa limestone.[2] The relationship of the so-called *Discorbis*, *Heterostegina* and *Marginulina* zones to the Catahoula has not been so definitely stated, due to the fact that the Catahoula changes "down-dip" so as to lose many of its surface characteristics. Applin, Ellisor, and Kniker[3] in describing these zones assign them to the Middle Oligocene and state:

> No marine Oligocene, as far as known, outcrops in Texas. However, from our study of well samples we find that marine Oligocene does exist in Texas. Well sections show a fossiliferous formation resting unconformably upon the Jackson and lying below beds comparable to the outcropping non-fossiliferous Upper Oligocene. The presence of *Heterostegina antillea*, Cushman, in the marine Oligocene beds of Texas, correlates these beds with the Antiqua (*sic*) formation of the West Indies, the type locality[4] of the Middle Oligocene, in which this species of Foraminifera is the key fossil. Some of the smaller Foraminifera of the Texas Oligocene are common to the Vicksburg group of Mississippi and Alabama. From the Jackson formation these Middle Oligocene sediments differ both paleontologically and lithologically.

At the time these zones were described the Vicksburg group was not recognized as being present in the area of the Texas coastal domes. Earlier in this paper it has been noted that 1,500 feet of beds are now assigned to the Vicksburg group in the stratigraphic position originally

[1] T. L. Bailey, "Frio Clay, South Texas," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 3 (March, 1932), p. 260.

[2] For an historical discussion of the stratigraphy of the Tampa limestone, or "silex beds," see C. W. Cooke and S. Mossom, *op. cit.*, pp. 78–97.

[3] E. R. Applin, A. C. Ellisor, and H. T. Kniker, "Subsurface Stratigraphy of the Coastal Plain of Texas and Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 9, No. 1 (January–February, 1925), pp. 79–122.

[4] T. W. Vaughan, *U. S. Nat. Mus. Bull. 103* (1919), p. 203.

indicated for these zones, *i.e.*, below the Catahoula and above the Jackson. The correlation of the *Heterostegina* zone with the Antigua formation of the island of Antigua, becomes much more difficult, if not impossible, when it is noted that T. W. Vaughan in his presidential address,[1] some five years later, before the Geological Society of America, has correlated the Antigua formation with the Glendon formation (middle Vicksburg) of the Gulf Coast, a horizon now known to lie a number of hundred feet below the *Heterostegina* zone.

The type figures of *Heterostegina antillea*[2] are not particularly clear. One is a photograph of a piece of limestone containing a number of *Foraminifera* of several kinds, the other two are photographs of sections. It is therefore evident, if Vaughan is right in his later correlation, that the species present in the *Heterostegina* zone is not *H. antillea*, or else that species has a much wider range in time than has heretofore been indicated for it.

The micro-fauna of the Tampa limestone is largely undescribed and the micro-faunas of the *Discorbis*, *Heterostegina*, and *Marginulina* zones are represented in the literature merely by faunal lists. The *Discorbis* zone is named for *Discorbis vilardeboana* d'Orbigny, at least that is the only *Discorbis* given in the faunal list. Applin, Ellisor, and Kniker also list the same species from the *Heterostegina* zone. Cushman has recently placed *Discorbis vilardeboana* under the genus *Valvulineria*[3] which would doubtless affect the name of the zone had not he and Ponton decided that the lower Miocene species of *Discorbis*, previously referred to *D. vilardeboana*, was in reality another species which he has referred to *D. candeina* d'Orbigny.[4] The narrowness by which the "*Discorbis* zone" of the so-called "Middle Oligocene" has escaped suffering a fate similar to that recently befalling the "*Discorbis* zone" of the Jackson well illustrates the danger involved in the use of generic names for zonal nomenclature.

This particular species, whether it be called by the generic name of *Discorbis* or *Valvulineria* and by the specific name of *vilardeboana* or *candiana*, occurs abundantly in the Tampa limestone at Falmouth Springs, Florida, associated with a fauna of warm water milioline forms which are strikingly similar to those present in the *Heterostegina*

[1] T. W. Vaughan, "Criteria and Status of Correlation and Classification of Tertiary Deposits," *Geol. Soc. Amer. Bull.*, Vol. 35 (1924), pp. 677–742.

[2] J. A. Cushman, "Fossil *Foraminifera* from the West Indies," *Car. Inst. of Wash. Pub. 291* (1919), pp. 49, Pl. 2, Fig. 1, Pl. 5, Figs. 1–2.

[3] *Idem, Bull. Scripps Inst. Oceanography*, Tech. Ser., Vol. 1, No. 10 (1927).

[4] J. A. Cushman and G. M. Ponton, "The *Foraminifera* of the Upper, Middle, and Part of the Lower Miocene of Florida," *Florida Geol. Survey Bull. 9* (1932), p. 88.

zone. The writer is therefore suggesting the strong probability that the *Heterostegina* zone and perhaps the *Discorbis* and *Marginulina* zones also should be correlated with the Chattahoochee formation, or Tampa limestone as the "down-dip" or seaward facies of the Catahoula. However, until the micro-faunas of the type Tampa, and of these zones are properly described and figured the correlation can not be other than suggestive.

Not a great deal of accurate information has been published concerning the thickness of the Catahoula formation. Shearer[1] estimates that it may possibly reach 1,000 feet in the southern part of Catahoula Parish, and states that it is about 600 feet thick in The Texas Company's Harris-Hyman well No. 1.

Matson[2] has published a graphic log of the Leesville Light and Waterworks Co., Limited, well, Leesville, Vernon Parish, on which he has indicated that the Hattiesburg extends to a depth of 161 feet; the Catahoula from there to 762 feet; the Fayette to 920; and from that depth to 1,482 feet he calls "Older Eocene." This would give the Catahoula a thickness of 601 feet if his correlation based on "logs and samples of cuttings" is correct. The presumption is very strong, however, that it is not correct, and that both the "Fayette and Older Eocene" recorded are of Catahoula age, for Haase[3] has recently recorded the base of the Catahoula at 1,757 feet in the Exchange Petroleum Company (White-Grandin No. 1) in the S.W. $\frac{1}{4}$, N.E. $\frac{1}{4}$, S.W. $\frac{1}{4}$ of Sec. 29, T. 3 N., R. 7 W., a point some 10 miles northeast of Leesville and on the strike of the beds.

The recording of "Fayette sandstone," on the same page, in a well at Pineville, in Rapides Parish, is also in error, for the Catahoula is definitely underlain by marine Vicksburg in that vicinity. His figure of 800 feet for the Catahoula in this well is his maximum figure, and is at least 500 feet too small for that portion of Rapides Parish.

M. T. Halbouty[4] has recently recorded these zones from the Yount-Lee Oil Co., Houssiere-Latrille well No. 10 in the Jennings field, Acadia Parish. He estimated the top of the *Discorbis* zone to lie at a depth of 7,177 feet and to have a thickness of 282 feet. He described these zones as follows:

[1] H. K. Shearer, *op. cit.*, p. 437.

[2] G. C. Matson, *U. S. Geol. Survey Prof. Paper 98* (1916), p. 214.

[3] F. M. Haase, *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 6 (June, 1932), pp. 608–09.

[4] M. T. Halbouty, "Vicksburg Formation in Deep Test, Acadia Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 6 (June, 1932), pp. 609–10.

The only cores obtained from this zone are from 7,445 to 7,446 feet, immediately above the *Heterostegina* zone. The cores were of gray, very hard and well cemented, calcareous, friable shales, and the residue consisted of fine to medium-grained quartz, chert, magnetite, abundant pyrite, siderite, gray shale, shell fragments, sponge spicules, and typical *Discorbis* zone *Foraminifera*.

The *Heterostegina* zone was found at 7,459 feet, the core at that depth being a gray, sandy limestone with numerous *Heterosteginoides* sp. This zone extends to 7,604 feet, a thickness of 145 feet of limestone, sandy calcareous clays, and shales.

Below the *Heterostegina* zone are 512 feet of greenish gray calcareous sandy shales and non-calcareous packed sands which are correlated with the *Marginulina* zone. The cores obtained were mostly sands and the foraminifers collected from the few shale cores were of no definite diagnostic value.

The contact with the Vicksburg group is placed at 8,116 feet.

These zones are also reported present at Vinton, Sulphur, Hackberry, Starks, Lockport, White Castle, Black Bayou, Bayou Bouillon, Sorrento and Port Barre.[1]

HATTIESBURG[2] AND PASCAGOULA[3] FORMATIONS; FLEMING CLAY[4]; LAGARTO CLAY[5]

There has been little information published on the outcropping formations which overlie the Catahoula and underlie the Pliocene and

[1] *Texas Gulf Coast Oil Scouts Association and South Louisiana Oil Scouts Association Bull. 1* (1930), p. 45.

[2] Originally described by L. C. Johnson, "The Miocene Group of Alabama," *Sci.*, Vol. 21 (1893), p. 90, as follows:

"More remote from the Great River (Mississippi), and southing farther, the less silicious the formation becomes, at Hattiesburg, and on that part of Leaf River from Okatoma to Roger's Creek, and on Chickasawnay above Leakesville, a third phase (of the Grand Gulf) is exhibited, abounding in phytogene remains—almost lignitic. This is the Hattiesburg phase or formation."

[3] Originally described by L. C. Johnson, "The Miocene group of Alabama," *Sci.*, Vol. 21 (1893), p. 90, as follows:

"A fourth manifests itself below Leakesville on the Chickasawnay, on the Lower Leaf River and Pascagoula—being clays of a more tenaceous quality—abounding in specks and nodules of calcareous material, and in a few places holding shells of mollusks. One locality of the last, where first discovered, is the Shell Landing below Roberts' Bluff, four miles south-west of Vernal postoffice. This is the Pascagoula phase or formation."

[4] The writer has not been able to examine the original description of the Fleming which A. C. Veatch, *U. S. Geol. Survey Prof. Paper 46* (1906), p. 43, states was named by W. Kennedy, in *Third Ann. Rept. Geol. Survey of Texas* (1892), pp. 62–63. However, from E. T. Dumble, "The Geology of East Texas," *Univ. Texas Bull. 1869* (1918), pp. 221–22, is taken the following statement:

"The Fleming clays were so named by Kennedy from the exposures near Fleming on the Missouri, Kansas & Texas Railway east of Corrigan. His description follows:

"The deposits are best seen in the neighborhood of Fleming, where, a little west of the station, the Trinity and Sabine Railway line passes over a high hill made up entirely of them. The same clays also occur in a cut on the line of the Southern Pacific Railway about a mile and a half north of Summit station, in Tyler county.

"The clays are dark blue, pale blue, brown, red, yellow and pale green in color.

younger gravel deposits in Louisiana. Veatch,[1] in discussing the outcrop of these beds, referred them to the Fleming clay and stated:

> The Fleming clay, which was so named by Kennedy in 1892 . . . consists of green or bluish green calcareous clays, differing from the underlying Catahoula beds in the presence of numerous small white calcareous nodules and the absence of the characteristic Catahoula sandstone layers. Near its base it often contains a bed of bright-red clay, which forms a convenient line of parting. These beds produce a stiff, heavy soil that is often black and resembles the soils of the Cretaceous prairies. Except where deeply covered with the surficial sands and gravels, these are commonly quite distinct from the coarse, sandy soils of the Catahoula formation.

Although these deposits represent less truly littoral sediments than the Catahoula beds, extended search has failed to reveal any marine remains except near Burkeville,[2] Newton County, Texas, where a brackish-water

---

They occur thinly laminated, or partially stratified and massive and have a strong tendency to joint or break into cuboidal blocks with a conchoidal fracture. The most important bed of clay in this group is a blue clay, partially stratified, but showing a tendency to break up into little blocks, and containing numerous concretions of carbonate of lime. This clay is perfectly smooth in texture and graduates into the underlying bed of red clay without any break except that of color, and the absence of the limy concretions which apparently do not occur in the red clay. At least where the beds were examined none were found. The red clay is in every other respect similar to the blue.

"Pale green, pale blue and brown clays are found overlying the blue limy clays at the different exposures, but occur most abundantly in the north of Summit station. These colors are not so persistent as the blue, and are probably due to some local cause.

"These clays in this portion of the State are overlain by and associated with a series of gray sands, which are mostly coarse-grained, sometimes massive, and in localities cross-bedded and stratified. The typical exposure seen at Fleming shows them to be gray stratified sand containing fossil palm in great quantities, with numerous quartz, jasper and other pebbles, and to have at that locality a thickness of twenty feet.

"These clays and sands occupy a belt from 15 to 25 miles in width and are followed by the deposits referred to the Lafayette."

[1] Originally described by E. T. Dumble, "The Cenozoic Deposits of Texas," *Jour. Geol.*, Vol. 2 (1894), p. 560, as follows:

"The Lagarto division includes a series of sands and clays of a different character from the Lapara, and overlying them. It comprises light colored clays—lilac, lavender, sea-green, greenish brown and mottlings of these colors—jointed and showing many slips. In places the upper portion contains a considerable amount of sand, gravel, or lime, and the change in a single stratum from one kind of rock to another takes place within a very few feet. In localities where the lime predominates it closely simulates the Reynosa. Where the limestone or calcareous sandstone caps the clays, strings of limestones extend downwards into them for a distance of six or eight feet. The clays contain quantities of semi-crystalline limestone pebbles with manganese dendritions, and indeed, manganese appears to be one of the characteristics of the clay wherever found. The upper portion of the beds is usually a sandstone. No fossils have been found in them."

[1] A. C. Veatch, *op. cit.*, p. 43.

[2] This fossiliferous outcrop a short distance west of the Sabine River at Burkeville, Texas, has been referred to the Chattahoochee by Harris: see paper by Veatch, *Louisiana Geol. Survey Rept.* (*1902*), p. 136; Frio clays—Oligocene by Maury; see *Bull. Amer. Paleont.*, Vol. 3, No. 15 (1902), p. 80; to the Eocene, with a long list of species by Hayes and Kennedy: see *U. S. Geol. Survey, Bull. 212* (1903), p. 53; to the Pliocene by Dall, who gives a long list of species, though placed in the Miocene by Deussen: see *U. S. Geol. Survey Water-Supply Paper 335* (1914), pp. 72–73; and on vertebrate evidence to either late Miocene or possibly early Pliocene by W. D. Matthew, in E. T. Dumble's "The Geology of East Texas," *Univ. Texas Bull. 1369* (1918), p. 225.

Oligocene fauna has been found in a local development of limestone 3 to 4 inches thick. These beds are particularly well developed on Neches River in the vicinity of Townbluff and extend east and west from that point in a belt 5 to 15 miles wide.

The thickness of the Fleming beds is not well known, though it has been estimated by Kennedy at 260 feet and by Veatch at 200+ feet.

Along Sabine River the dip of the Fleming formation is much less than that of the basal Catahoula beds, though it is apparently the same as that of the uppermost Catahoula, which is from 25 to 35 feet per mile.

A portion of the outcrop of these beds is shown on the geologic map accompanying Veatch's report and also on the map accompanying the paper by Harris[1] on oil and gas in Louisiana. The contact of these beds with the Catahoula is indicated as passing from a point just below Burr Ferry in Vernon Parish, past Leesville, to a point just southwest of Boyce in Rapides Parish.

A recent note by Haase[2] is accompanied by a map which shows this contact in greater detail. Haase states:

> In fixing the contact, the writer has used the presence or absence of calcareous material as the principal determining criterion. Non-calcareous clays were mapped as Catahoula; calcareous clays, in places also bearing many small white calcareous nodules, were mapped as Fleming. Other criteria were helpful, but the one mentioned was most readily applied in the field. At the places shown on the map by crosses, the contact is definite enough to enable one to determine the elevation as shown.

Matson,[3] in his paper on the Catahoula sandstone, gives the log of a well at Leesville, in Vernon Parish, on which the upper 161 feet are assigned to the Hattiesburg clay. And, on p. 225, he states:

> The relation of the overlying Miocene to the Hattiesburg clay (considered Oligocene by Matson) is unconformable, and this permits the separation of what has been called the Fleming clay in Louisiana and along the eastern border of Texas into two parts. The lower part, which, from its stratigraphic relations is included in the Hattiesburg clay, is more sandy and much less calcareous than the overlying Miocene clays.

In the same paper, p. 225, Matson gives the following discussion and re-definition of the Pascagoula clay.

> A series of blue, green, and gray clays, locally calcareous, with interbedded sands and more rarely sandstones, lying unconformably above the Hattiesburg clay, has been called the Pascagoula clay. This formation is locally fossiliferous and has furnished remains of marine or brackish-water invertebrates at Shell Bluff and Givhens Landing, on Chickasawnay River,

[1] G. D. Harris, *U. S. Geol. Survey Bull. 429* (1910).

[2] F. M. Haase, "Catahoula-Fleming Contact, Vernon Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 6 (June, 1932), pp. 608–09.

[3] G. C. Matson, *U S. Geol. Survey Prof. Paper 98* (1916), p. 17.

Miss., and in numerous wells in the southern part of the State. A somewhat different fauna has been obtained from the formation at Pine Prairie and southwest of Alexandria, La., and at Burkeville, Texas. The formation ranges in thickness from about 250 feet in Alabama to 450 feet near Mississippi River in Louisiana and along the Gulf coast in Mississippi. In western Louisiana and eastern Texas the thickness has not been accurately determined, but it is thought to be about 250 or 300 feet. Local variations in thickness are to be expected, because the Pascagoula clay is overlain unconformably by sands and clays of Pliocene age and rests unconformably on the Hattiesburg clay.

The Pascagoula clay differs from Johnson's Pascagoula phase or formation by including the portion of his Fort Adams or Ellisville phase extending from Tunica, La., to Columbia, Miss. The type locality is, however, the same, and the difference is largely due to a more thorough understanding of the distribution of the formation. West of Mississippi River the Pascagoula clay extends across southern Louisiana and eastern Texas and includes the upper portion of what Veatch called the Fleming clay.

The fauna from southwest of Alexandria that Matson referred to and placed in the Pascagoula had previously been described by Dall[1] who considered it Pliocene. The writer possesses an excellent collection of fossils made by Frank Lewis of Alexandria. In a letter to the writer, May 19, 1933, Perry Olcott on the authority of Mr. Russom of the Sinclair gives the locality as Sec. 28, T. 3 N., R. 2 W. It contained, in addition to a large number of brackish water clams and snails, an abundance of two varieties of *Rotalia beccari*, several species of *Elphidium*, and a great variety of *Ostracodes*.

The following year Matson[2] published a geologic map of Louisiana on which he showed the distribution of the Hattiesburg clay and the Pascagoula clay. Graphic logs of two wells are shown also (on p. 157) to illustrate the character of the Pascagoula clay. On one of these—the well of Gulf Land and Lumber Co., Fullerton, Vernon Parish—more than half of the Pascagoula is plotted as "Sand (?) with water." On the log of the other well at Bass, East Baton Rouge Parish, the portion attributed to the Pascagoula is obviously Citronelle or younger, as it records numerous sand beds with chert pebbles an inch or less in diameter.

Whether these beds lying below the "Citronelle" and above the Catahoula formation and "*Discorbis* zone" should be called "Fleming," or "Hattiesburg clay," or "Pascagoula clay," or "Lagarto clay" (a name which the United States Geological Survey has used on its preliminary edition of the Geologic Map of Texas, 1932, for the beds

[1] W. H. Dall, "On a Brackish-Water Pliocene Fauna from the Southern Coastal Plain," *U. S. Nat. Mus. Proc.*, Vol. 46 (1913), pp. 225–27.

[2] T. C. Matson, "Louisiana Clays," *U. S. Geol. Survey Bull. 660–E* (1917), pp. 147–58.

outcropping at the type section of the Fleming) is impossible to determine at the present time due to the lack of detailed field studies in the area of the outcrop. In the absence of detailed comprehensive paleontologic studies, it is likewise impossible to make any accurate separation between Miocene and Pliocene. It has been generally considered that the presence of *Rangia cuneata* indicated Pliocene or younger beds. The writer has often observed that species in cores from depths as much as a thousand feet below the lowest bed of gravel shown in the driller's log. It seems probable, therefore, that there is a considerable thickness of Pliocene sediments lying below the Citronelle gravels.

The maximum thickness of these beds which lie below the Citronelle gravels and above the Catahoula and *Discorbis* zone is still rather difficult to estimate accurately for Louisiana. It is certainly much greater than any heretofore published estimates, and probably is greatest in the region adjacent to the Mississippi flood plain.

Halbouty[1] did not record the thickness of the Citronelle in the Yount-Lee Oil Company's Houssiere-Latrille well No. 10 at Jennings, but his figure of 7,177 feet as the depth to the top of the *Discorbis* zone is helpful. Unfortunately there is no gravel shown on the log of this well; but in an earlier paper by Barton and Goodrich[2] the base of the Citronelle is placed in the neighborhood of 1,100 feet, for this field. Even if the base of the Citronelle lies a thousand feet deeper on this dome, there would still be left a thickness of more than 5,000 feet of "Fleming," "Hattiesburg," "Pascagoula," "Lagarto," before the *Discorbis* zone is reached. Along the line of the Southern Pacific Railroad this interval may reach as much as 6,000 feet, with the base of the Citronelle gravels lying at depths of from 1,200 feet to 2,500 feet, and the top of the *Discorbis* zone lying at depths of from 7,000 feet to more than 8,500 feet.

The study of this stratigraphic interval is complicated by the fact that these brackish-water beds become marine in the southern tier of parishes, and abundant marine faunas have been obtained from wells in southern Cameron, Terrebonne, Lafourche and Plaquemines parishes, which may be correlated with the Choctawhatchee and Alum Bluff groups of the Florida Miocene. Micropaleontologists will find the recent paper by Cushman and Ponton[3] of a great deal of assistance

[1] M. T. Halbouty, *op. cit.*, pp. 608–09.

[2] D. C. Barton and R. H. Goodrich, "The Jennings Oil Field, Acadia Parish, Louisiana," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, No. 1 (January, 1926), p. 85.

[3] J. A. Cushman and G. M. Ponton, "The *Foraminifera* of the Upper, Middle, and Part of the Lower Miocene of Florida," *Florida Geol. Survey Bull. 9* (1932).

in naming the *Foraminifera* encountered in these horizons. It should be used in conjunction with an earlier paper by Cushman[1] in which many of the listed species are figured.

Pliocene and Pleistocene Periods

citronelle (?) formation[2]

The beds to be described under the heading Citronelle (?) formation have been variously referred to in the older Louisiana geologic literature under the terms "Drift," "Orange sand," and "Lafayette gravels." They apparently correspond to the formations currently named "Lissie"[3] and "Reynosa"[4] in Texas, and are in part at least Pleistocene in age.

[1] J. A. Cushman, "The *Foraminifera* of the Choctawhatchee Formation of Florida," *Florida Geol. Survey Bull. 4* (1930).

[2] Named by G. C. Matson, "The Pliocene Citronelle Formation of the Gulf Coastal Plain," *U. S. Geol. Survey Prof. Paper 98* (1916), pp. 167–92. His original definition is quoted.

"The name Citronelle formation is applied to sediments of Pliocene age, chiefly nonmarine, that occur near the seaward margin of the Gulf Coastal Plain, extending from a short distance east of the western boundary of Florida westward to Texas. Citronelle, a town on the Mobile & Ohio Railroad, in the northern part of Mobile County, Ala., was chosen as the type locality because of the excellent exposures of the formation in its vicinity, especially to the north along the railroad for a distance of 3 or 4 miles. The best collection of fossils was obtained from a clay bed a few miles south of the type locality, near a station called Lamberts, where a flora sufficiently well preserved to permit correlation of the beds with the Pliocene was found."

[3] Named by Alexander Deussen, *U. S. Geol. Survey, Water-Supply Paper 335* (1914), pp. 78–80, whose original definition is quoted:

"The lithologic unit now to be described is called the Lissie gravel after the town of Lissie, in Wharton County, Tex., where it typically occurs.

"As here interpreted, the Lissie gravel represents the time equivalents of the middle and of the lower part (or gravel portion) of the lowest of the three Pleistocene terraces described on pages 82–83.

"The Lissie gravel is believed to represent the coalescing alluvial fans which were spread out at the mouths of the valleys of the streams which discharged into the sea during some parts of Pleistocene time, possibly the early and middle parts. It is further believed that the gravel was later elevated and eroded, proof being found in the fact that the terraces which grade laterally into the lower or interior part of this gravel lie 50 to 70 feet above the lowest of the Pleistocene terraces, whereas the lowest Pleistocene terraces grade into the upper part of the gravel and into the Beaumont clay. Furthermore, a few isolated unconformities are exposed in the southwest. Following this erosion epoch came a depression of the land and an invasion of the sea, in a later portion of Pleistocene time, submerging in part the area occupied by gravel. On the floor of this Pleistocene sea, on top of the eroded gravels, was spread unconformably another layer of gravel, similar in composition and consisting in part of reworked and eroded products of the first layer. With the gradual deepening of the sea and the lessening gradients of the streams, deposition of gravel ceased and in place of it was formed a deposit of silt, sand, and clay to which has been given the name Beaumont clay.

"Lissie gravel, therefore, as used in this report, includes all the gravels, these being characterized by more or less uniform lithologic composition, albeit separated by an unconformity into lower and upper portions."

[4] Named by R. A. F. Penrose, Jr., *Texas Geol. Survey First Ann. Rept.* (1890), p. 63, whose description is as follows:

"REYNOSA LIMESTONE.—The Mexican town of Reynosa, in the State of Tamaulipas, on the Rio Grande, is situated on a hill rising some fifty feet above the level of the river and composed of a hard white limestone. This is made up of very hard calcareous

Matson[1] described the lithology of the Citronelle formation as follows.

The Citronelle formation is predominantly sandy but contains varying amounts of clay in the form of thin layers or lenses. The relative proportion of materials of different kinds varies from place to place, and in any one section it varies from top to bottom, though in general sand is everywhere abundant and at many places there is some gravel. The proportion of sand is greatest near the base, and the formation contains more sandy material in the vicinity of the principal drainage lines than in the interstream spaces. There is also a larger percentage of sand and gravel near the landward than the seaward margin of the formation, though in making comparisons it is necessary to consider large masses and to choose localities bearing about the same relations to the principal lines of drainage, because more sand and gravel will be found in the vicinity of large streams near the coast than on some of the interstream spaces farther inland.

The sands of the Citronelle formation are sufficiently rounded to indicate that they have been subjected to extensive attrition. The pebbles vary greatly in degree of rounding; many of them are much waterworn and resemble pebbles found on the beach, others are only slightly rounded, and still others are subangular. The sand is predominantly quartz, and the pebbles in the Mississippi embayment are mostly chert, with a somewhat smaller percentage of crystalline quartz and quartzite. Many of the chert pebbles contain cavities lined with chalcedony in the form of agates or geodes, and a large number of them are fossiliferous, containing fragments of corals, crinoid stem, and other organic remains such as are common in the Paleozoic limestones and chert. In Alabama there are many pebbles of quartz, with a subordinate percentage of quartzite, but in some places chert pebbles are numerous. In western Louisiana the pebbles are mostly quartz with some admixture of chert.

Certain peculiarities in the distribution of materials in the Citronelle formation are worthy of mention. In Mississippi the outliers are in general composed of coarse subangular chert gravel, with a varying percentage of small, well-rounded quartz pebbles. In Louisiana and Alabama quartz gravel is common. The coarse pebbles have in a measure the same composition and evidently came from a common source, and the same is true of the fine pebbles. The coarse subangular fragments are mostly chert and have been subjected to fluviatile wear with very little subsequent rounding by waves, but many of the finer, well-rounded pebbles are quartz and have doubtless been

nodules, one-half inch to over three inches in diameter, white to creamy-brown in color, and in places showing a concretionary structure imbedded in soft white material of the same composition. This deposit lies on the sands of the Fayette series, which are exposed at the water's edge. Though usually hard, yet in places on the surface it is soft and crumbly, and in this softer material were found many specimens of *Bulumulus alternatus*, Say, a shell found now in great quantities on the Rio Grande. These prove the late origin of at least the material in which they were imbedded, and it apparently blends into the harder rock. But unfortunately time did not permit a thorough investigation of the region, and consequently, though it is probably true that the whole of the limestone is of the same late origin, its relations and extent have not been studied. It undoubtedly overlies the Fayette Beds, as this is proved by the small outcrop of the latter at the water edge at Reynosa. Similar limestones are said to be found in various parts of Hidalgo County, and that in digging wells they are passed through for about thirty feet, when they find water in an underlying sand or sandstone (Fayette Beds?)."

[1] G. C. Matson, *op. cit.*, pp. 173–75.

shaped by prolonged subaqueous erosion. Probably the subangular material was brought directly from its original source, and the fine, well-rounded material was subjected to wave erosion by being deposited in some one or more of the older formations of the Coastal Plain, from which it was obtained by Pliocene streams. This conclusion seems warranted because the gravel is a poorly assorted aggregate of material of all sizes from sand to pebbles an inch or two in diameter. If the gravel had been subjected to wave action during Pliocene time it would have been assorted, and it is therefore inferred that the perfect rounding of the small pebbles was accomplished by wave action during earlier geologic periods.

The clays vary greatly in character, some of the beds being relatively pure and others distinctly sandy. On the whole the sandy clays predominate, and in many places thin layers of sand are found in the clay beds.

The Citronelle formation has a very wide range in color. Doubtless when fresh some of the materials included in the formation were either blue or gray with small percentages of red and yellow, but nearly all the exposures available for observation at the present time have been subjected to so much weathering that the original colors have been partly or wholly obliterated. The sands in most of the sections are either orange or red, though near the surface some of them are yellow. This predominance of the orange and red colors on weathered surfaces led to the designation of the materials in this formation, either wholly or in part, as "Orange sand." The clays vary in color according to the degree of weathering to which they have been subjected, beds that have been buried to sufficient depth to protect them from the oxidizing effect of the atmosphere or surface water being either pale blue or gray. Where the oxidation has been slight they are mottled, the first change producing spots or blotches of a light-red or peculiar purplish color. As the process of weathering continues the purple color disappears and a deep-red color predominates, and still further weathering changes the red color to pale yellow. The iron in the clay, which presumably causes the coloring, changes during the process of oxidation to hydrous oxide, and on complete weathering of the clay to a yellow color the iron becomes more or less aggregated into nodules of varying sizes. Somewhat similar aggregations of iron hydroxide occur in the sands in the form of concretions and geodes, or as shells inclosing cores of clay. In other places the iron accumulates in the form of plates cementing thin layers of sand or as a filling for more or less definite cracks that cross the strata at high angles. Where the iron hydroxide is disseminated among the sand grains or pebbles it transforms the bed into a sandstone or conglomerate. This cementation apparently takes place near the surface and as a rule does not extend for any great distance along a bed, so that in most places the sandstone and conglomerate are in the form of blocks of varying sizes. The irregularity in size and shape of these blocks usually prevents them from being utilized in construction, even where they are firmly cemented, but south of Citronelle, at the 28-mile siding on the Mobile & Ohio Railroad, a hard sandstone belonging to this formation has been quarried to a depth of over 5 feet, and the rock obtained at this locality has been used in the construction of a church.

The texture of the formation in any particular locality depends entirely on the arrangement and relative percentages of the different kinds of materials. In general, the sands form more or less continuous beds containing

lenses of pebbles or clay that in some places have considerable horizontal extent and in others are limited to only a few feet. Many clay lenses are only a few feet to a few rods in extent, though in places they interlock with other lenses lying above and below them, and in that way present the appearance of a continuous bed, unless it is possible to examine a section in detail. In the sands cross-bedding and cross lamination are the rule rather than the exception, the layers of clay and pebbles in many places being inclined at high angles. Smooth, even bedding is comparatively rare except in the clay lenses.

In this formation, as in many others, pebbles of clay are common, occurring at many stratigraphic horizons and having a wide geographic distribution. Most of them are more or less perfectly rounded balls of clay embedded in sand in such a way as to form a lenticular clay conglomerate. In places there are more or less rounded blocks of clay in which the original lamination is still preserved. Here and there this lamination coincides in direction with that of the sands, but as a rule it differs. Doubtless many of the pebbles were eroded from the subjacent clay by the currents that transported the sand. Some of the pebbles and probably most of the angular fragments were derived from the undercutting of small cliffs developed by waves or currents. This explanation for blocks of clay embedded in sand was first suggested by T. Wayland Vaughan to account for similar clay fragments found in some of the sands of the Wilcox formation, but it is also applicable to such clay fragments in the Citronelle formation.

The published information concerning the thickness of the Citronelle (?) formation in south Louisiana is very unreliable. East of the Mississippi River this information is confined largely to a series of graphic well logs on which Matson[1] placed his correlation. These wells are located at Bass (106-mile siding) in East Baton Rouge Parish, at Bayou Sara in West Feliciana Parish, and at Woodville, just north of the Louisiana line in Mississippi. On one of them, the Bayou Sara well (elevation 50 feet), the base of the Citronelle is placed at slightly more than 300 feet, and the base of the Pascagoula clay at (?) slightly more than 500 feet, below which to a depth of slightly more than 2,300 feet the formations are indicated as Oligocene and Eocene. To explain such correlations, one must surmise that they were made without the aid of paleontology, and on the assumption that these formations had a similar thickness in Louisiana to what they were supposed to have in Alabama. To illustrate how far out of line these estimates really are, the author cites a well drilled by the Vacuum Oil Company, in T. 1 S., R. 5 W., near Angola, in West Feliciana Parish, the cores of which were examined by the author some years ago. The log of the well shows abundant sand and gravel to a depth of 974 feet, which can scarcely be considered older than Pliocene, and which must, therefore, be referred to the Citronelle (?) formation. The first Miocene *Foraminifera* were encountered in a core at 3,213 feet. The last

[1] G. C. Matson,, *op. cit.*, Pl. XLIII.

core examined was from a depth of 4,425–43 feet and was certainly not older than Catahoula in age. The well was abandoned at 4,626 feet without having passed through the Catahoula. From the evidence afforded by the Vacuum well, the present writer would be more inclined to suspect that the beds of gravel shown in the log of the Bayou Sara well between 1,500 feet and 1,900 feet belonged to the Citronelle (?) than to "Oligocene and Eocene."

West of the Mississippi, Howe and Moresi[1] have shown that Pliocene and younger gravels which may be referred to the Citronelle (?) extend to a depth of 3,300 feet in wells drilled on the sides of Jefferson Island, in Iberia Parish. What portion of these gravel deposits in south Louisiana should be referred to the Pliocene, and what to the Pleistocene is still very difficult to determine. The writer, however, is under the impression that most of the beds Matson referred to the Citronelle in his well correlation should in reality be referred to the Pleistocene.

Like the previously discussed Miocene, the Citronelle (?) gravel horizon tends to become marine in the extreme southern part of Louisiana, and in the salt dome section of southwest Louisiana, between the line of the Southern Pacific Railroad and the Gulf, it is not uncommon for wells to encounter beds of *Rangia cuneata* within the horizon which carries gravels. As many of the overlying Pleistocene and Recent sediments of the lower Mississippi delta adjacent to the present shore line of the Gulf of Mexico are likewise fossiliferous, some difficulty is encountered in drawing a sharp line between the Pleistocene and the Pliocene. For a comprehensive and able discussion of the *Mollusca* encountered in early wells drilled in Terrebonne Parish the reader should consult the paper by Harris[2] which contains extensive lists of fossils determined by Miss Maury. In commenting on these wells, the statement is made:

> It is interesting to note, in studying shells from the Gymnasium well at New Orleans from a depth of only 1,200 feet, that they comprise more new species, or species not now known to be living in the Gulf waters, than are obtained from the much deeper wells in Terrebonne Parish.

One of the wells was drilled to more than 3,000 feet, but all beds encountered were considered by Miss Maury to be Pleistocene.

Various names have been applied to the outcropping Pleistocene formations which overlie the Citronelle (?) gravels. The Beaumont

[1] H. V. Howe and C. K. Moresi, *Louisiana Dept. Conserv. Geol. Bull. 1* (1931), p. 97.

[2] G. D. Harris, "Oil and Gas in Louisiana," *U. S. Geol. Survey Bull. 429* (1910), pp. 164–73.

clay[1] was mapped by Hayes and Kennedy as crossing the Sabine River just north of Orange and extending into Louisiana along a line which passes just to the north of Lake Charles. These beds carry abundant marine fossils in wells scarcely more than 20 feet deep at Lake Charles. East of the Mississippi, the famous locality at Port Hudson, in the northwest corner of East Baton Rouge Parish, has furnished the type locality for a brackish water phase of the late Pleistocene.[2] However, to emphasize the difficulty of attempting to assign definite formational names to the varied deposits of late Pleistocene time, the writer quotes the still appropriate remarks of Harris,[3] made nearly thirty years ago.

The longer the geology of southern Louisiana is studied the more futile appears the attempt to make satisfactory subdivisions in the Quaternary deposits—subdivisions that have any definite time or structural limits. Differences in conditions of deposition during the same period of time have produced results that vary greatly in different localities. The same differences in conditions of deposition that we see to-day at different places in southern Louisiana, producing the sea-marsh clays with vegetable and brackish-water organic inclusions, the yellow sand ridges with an abundance of purely marine life, the purely fresh-water alluvium, and the alluvium intermingled with marine sands at the mouths of the larger rivers, all seem to have existed throughout Quaternary times. The mistake that has been made in assigning to the "Port Hudson group" a special place in geologic time may well be illustrated by the case of the casual theater-goer who drops in on a play on the last evening of the season and observes with care and interest the personae, costumes, etc., throughout the different acts and scenes of the performance and afterwards records the fact that this particular play was given at this place at this particular time. The inveterate theater-goer, on the other hand, may see nothing of special interest in these facts, for he may know that that play had been running at that place not only that particular night but during the whole season. The swamp condition of the "Port Hudson" has been truly reproduced, with its clays, "black muck," and logs, to a depth of over 800 feet in the wells of southwestern Louisiana; the estuarian clay condition (Pontchartrain clay) is accurately reproduced at depths of 80, 500, 1,200, and best of all at 1,800 feet beneath the surface; the marine sands may be found at various depths. Thick beds of so-called Lafayette gravel are often interspersed with these "Port Hudson" elements.

It seems, therefore, that if there is anything to be gained by applying a name to clays that were evidently deposited in brackish-water bays, estuaries, and lakes along the Gulf border, some such term as "Pontchartrain clays" may be used, with the understanding, however, that the name shall denote a particular kind of deposit or phase of deposition having no special time value.

[1] Named by C. W. Hayes and William Kennedy, *U. S. Geol. Survey Bull. 121* (1903) pp. 27–29.

[2] See E. W. Hilgard, *Amer. Jour. Sci.*, 2nd. Ser., Vol. 48 (1869), p. 332.

[3] G. D. Harris, "Underground Waters of Southern Louisiana," *U. S. Geol. Survey Water-Supply Paper 101* (1904), pp. 21–22.

So, too, the deposits, mainly alluvial, containing a large amount of vegetable matter, especially stumps and trunks of trees, may, if necessary, be classed as Port Hudson clays; and marine sands may be referred to as Biloxi sands; but in all cases the terms must be understood as denoting mere phases of deposition, not stratigraphic units.

DISCUSSION

A. F. CRIDER, Shreveport, Louisiana (written discussion received, May 4, 1933): Dr. Howe has pointed out two objections to the use of the term Wilcox. These are (1) lack of priority and (2) the better type locality of the name Sabine. He has reviewed the history of the use of the various names for the assemblage of sand, clay, lignitic material, calcareous marl, and limestone which come in between the Claiborne above and the Midway below.

If priority alone shall govern, then the term Lignitic, as defined and used by Hilgard in Mississippi and adopted by Smith in Alabama, should stand. But by general usage and in accordance with the rules of geologic nomenclature, lithologic names of formations have been discarded for locality names. Priority of use is not, therefore, the absolute basis for the establishment of names of geologic formations.

In Wilcox County, Alabama, the present type locality for what has been called "Lignitic" by Hilgard and Smith, the entire Wilcox group, as then known, is exposed. Dr. Smith, as early as 1887, separated this group into four sub-stages or formations, and carefully described each, giving the names of the characteristic fossils in each marine bed.

The objection has been raised that the time equivalent of the Wilcox, in Wilcox County, Alabama, is not traceable across Mississippi, Arkansas, and the upper gulf embayment, and for that reason, the term "Sabine" should be substituted for the name Wilcox, because of the better type locality of Sabine.

Let us analyze the objection. Veatch says:[1]

> In Alabama, this formation, which has long been called the Lignitic, contains several fossiliferous horizons that are closely related from a paleontologic standpoint, but show faunal differences which have led to the recognition of four substages. . . . No distinctive marine fossils have yet been found in the lignitiferous time equivalent of this formation in Mississippi,[2] Arkansas and the upper embayment region, but along the Sabine River in Louisiana and Texas, in the same position relative to the embayment as the Alabama deposits, are developed fossiliferous beds showing the same facies.

Veatch recognized the type section in Alabama as being all that could be wished for and admitted that the Sabine section occupies the same relative position as the Alabama section. The faunal assemblage of the Lignitic was well known, and he added nothing new to this phase of the formation, and there was nothing new added to the near-shore deposits. All that Veatch ever claimed for the name Sabine was that it was the same as the old term, Lignitic.

My description of the type section of the Wilcox may not have been as clear and complete as it should have been, but it was not the fault of the type locality. It does not seem justifiable, at this late date, to change the name of Wilcox to Sabine because of the better type locality of the latter.

[1] A. C. Veatch, "Geology and Underground Water Resources of Northern Louisiana and Southern Arkansas," *U. S. Geol. Survey Prof. Paper 46* (1906), p. 35.

[2] As a matter of record the marine Wilcox has been discovered in eastern Mississippi.

Recent drill cores, far down the dip from the outcrop of the Wilcox, show that only a small part of the Wilcox is exposed at the surface from Alabama to Texas. Approximately 1,700 feet of Wilcox has been recognized in a well in southern Alabama and in wells drilled far down the dip of the Sabine uplift, while Veatch places the thickness of the formation at his type locality as only 900 feet. New beds come in down the dip from the outcrop, so that the Wilcox, far down the dip, differs more from what it is at Veatch's type locality, than the original Lignitic in Alabama differs from Veatch's type locality of the Sabine in Louisiana.

In all of the literature since 1906, the type locality of the Wilcox has been referred to Wilcox County, Alabama. There has been no confusion in the minds of geologic writers on this point.

If the question of substitution of the name Sabine for Wilcox is to be considered at this late date, after the name Wilcox has been in general use in the literature of all of the states where the formation is exposed at the surface, in the United States Geological Survey publications, and in foreign publications, let it be on priority alone and not because of the better type locality of Sabine.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), PP. 656-679, 11 FIGS.

STRUCTURE AND STRATIGRAPHY KELSEY ANTICLINE UPSHUR COUNTY, TEXAS[1]

A. R. DENISON,[2] A. E. OLDHAM,[3] and J. W. KISLING, JR.[2]
Fort Worth, Texas, Shreveport, Louisiana, and Tyler, Texas

ABSTRACT

The writers describe an area in western Upshur County, northeast Texas, where surface and subsurface evidence demonstrates the presence of an anticline having more than 100 feet of surface and 300 feet of subsurface closure. They trace the geologic history of this area through Cretaceous and Tertiary deposition and demonstrate that the anticline first became a structural trap in Wilcox time. They reach the conclusion that the structure was formed too late to allow accumulation of oil in the Woodbine sand.

INTRODUCTION

Acknowledgments.—The writers are indebted directly and indirectly to many individuals for suggestions and helpful criticisms. Formation contacts, wherever possible, are based on paleontological evidence. These determinations are from several sources, but particular thanks are due N. L. Thomas and Harold Herndon. A. E. Oldham is responsible for all areal and surface geology, including stratigraphy. Subsurface geology and stratigraphy are by J. W. Kisling and geologic history by A. R. Denison.

Location.—The Kelsey anticline is located in Upshur County, northeast Texas, 7 miles west of Gilmer, the county seat. The anticline derives its name from the former post-office of Kelsey located on the axis of the structure at its south end. Its location with respect to important Woodbine oil fields is shown in Figure 1. Geologically, it is situated across the axis of the East Texas basin, if extended (Fig. 2). The uplift appears to separate what otherwise would be a continuous synclinal axis extending from Texas, northeast into Arkansas.

HISTORY OF DEVELOPMENT

The Kelsey anticline was discovered for the Amerada Petroleum Corporation by A. E. Oldham, then in its employ, in June, 1928. A

[1] Published by permission of Amerada Petroleum Corporation.

[2] Geologists, Amerada Petroleum Corporation, Fort Worth and Tyler.

[3] Geologist, Arkansas Natural Gas Company, Shreveport.

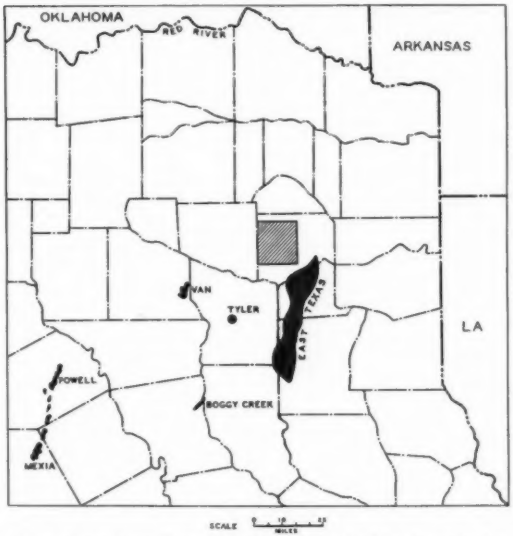


FIG. 1.—Map of northeast Texas showing principal oil fields producing from Woodbine sand and area discussed in this paper.

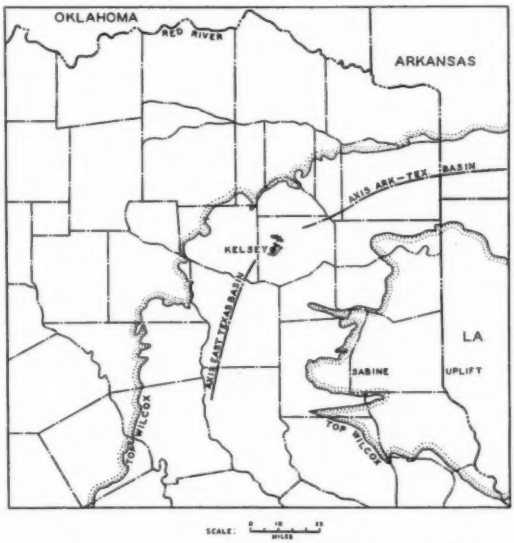


FIG. 2.—Map of northeast Texas showing normal outcrops of Wilcox formation, basin axes, and relation of Kelsey Wilcox inliers to these features.

TABLE I

GENERALIZED SECTION OF FORMATIONS FOR KELSEY AREA

System	Series	Group	Formation	Thickness in Feet	Character
Tertiary	Eocene	Claiborne	Weches	40	Glauconite and glauconitic clays, few fossils, weathering to iron ore in exposed areas
			Queen City	400	Alternating sands and clays, much recemented sand on surface. Lignites near top
			Reklaw	45	Fossiliferous, micaceous, glauconitic sands and clays, chocolate in color. *Venericardia planicostata* in abundance
			Carrizo	20	Argillaceous sand, non-fossiliferous. Claiborne in lithology
			Wilcox	798–1,030	Non-marine, clear quartz sand, gray micaceous sandy clay and lignitic clay
			Midway	591–645	Blue and gray clays with calcareous sandy streaks and siderite boulders. Bottom 25–50 feet calcareous
Cretaceous	Gulf		Navarro	550–600	Gray, calcareous, fossiliferous shale. Nacatoch represented by 100–150 feet of gray shaly sandstone, slightly glauconitic
		Taylor	Upper Taylor (Marlbrook)	180–200	Gray, calcareous shale and marl
			Pecan Gap	400–421	White and gray chalk, bottom 100 feet with calcareous shale breaks
			Lower Taylor	729–800	Light to dark gray shale and gray and greenish gray sandy shale and sand; shale slightly calcareous and may be micaceous and glauconitic. Sands may be limy and glauconitic
			Austin	40–65	Hard gray, fossiliferous chalk with hard gray, calcareous shale breaks, conglomerate at base
			Eagle Ford	65–75	Hard, dark gray, non-calcareous shale and sandy shale. Sandy material glauconitic and in places carries finely disseminated lignite

TABLE I (*Continued*)

			Woodbine	350–456	Predominantly sands and sandy shales with dark gray, greenish, purple, and red shales. Sands may be ashy, bentonitic, or chloritic with much lignite; and grains range from fine to small pebbles. Some shales are bentonitic and carry lignite. Purple and greenish shales give mottled effect. Near shore fossils are rare
	Comanche	Washita	Washita shale (Del Rio?)	25–42	Hard, brownish gray, slightly calcareous shale, containing specks of lignite and megafossils
			Washita limestone (Georgetown et cetera)	788	Hard, white and gray crystalline limestone and shaly limestone and hard gray calcareous shale
		Fredericksburg	Edwards, et cetera	257	Hard, pearl gray, finely crystalline limestone and dark gray, limy shale
		Trinity	Paluxy	343	Hard, white, gray and greenish, fine-grained lignitic sandstone and gray and red shales
			Glen Rose	843	Predominantly hard gray, crystalline limestone and gray, limy shale. Some gray, fine-grained, lignitic, micaceous sands and sandy shales, and red and green shales, are interbedded with limes and calcareous shales

block of acreage covering the structure was assembled in July and August, 1928. Early in 1929 a location was made by the corporation for the C. K. Wade No. 1 in the J. H. Fields Survey. Drilling commenced March 21, 1929, and the well was abandoned September 26, 1929, at a total depth of 6,153 feet. There was no additional development on this anticline until 1932, when the following wells were completed.

Pilot and Snebold's J. G. Ray No. 1, A. H. Woods Survey
Commenced, November 24, 1931. Completed, February 11, 1932
Gillett, Tarr, and Potter's D. A. Irons No. 1, D. B. Lucas Survey
Commenced, January 14, 1932. Completed, February 18, 1932
Mannus and Snuggs' G. C. Pool No. 1, S. J. Pounds Survey
Commenced, May 19, 1932. Completed, June 18, 1932
J. P. Evans' Mrs. S. A. Bell No. 1, Wm. McFadden Survey
Commenced, September 15, 1932. Completed, November 3, 1932

All of these wells were drilled on acreage included in the original block

of leases. All five wells penetrated the entire Woodbine section of Upper Cretaceous age and reached Washita limestone of Lower Cretaceous age. None reported an appreciable showing of oil or gas. As shown by the subsurface maps (Figs. 5, 6, 7), three of these wells are along the north-south axis of the structure, and one is east and one west of the axis.

STRATIGRAPHY

The description of the formations, both exposed and unexposed, which follows is primarily for the area of the surface structure and for the wells drilled on the structure. Many of the characteristics mentioned, however, are common to these beds throughout a much wider area than that discussed in this paper.

EXPOSED BEDS

EOCENE

Sparta.—This formation is present as a thin veneer capping the Weches hills and is typically coarse, white, friable sand.

Weches.—The Weches consists of glauconite and glauconitic clays, having a thickness of 40 feet in this area. The iron silicate of the glauconite weathers to the oxides which, being very resistant to erosion, hold up hills that are the most prominent topographic features in East Texas. There are few fossils in the Weches in this part of the East Texas basin.

Queen City.—Overlying the Reklaw is a section of alternating sands, clays, and sandy clays, having a thickness of approximately 400 feet. In this section, 110–130 feet above the base of the Reklaw, are a few scattered exposures of glauconitic sand which are correlated with the Omen member of Smith County and the region farther south. Alternating sand and clay layers form many seeps and springs which are conducive to leaching and redeposition of iron, so that the Queen City surface is characterized by considerable recemented ferruginous sandstone. Lignite layers are common especially in the upper 100 feet of section.

North of Rhonesboro, a considerable area is marked by an occurrence of white, evenly sorted, very fine-grained, quartzitic sandstone boulders. Reed impressions are common. The lithology is very different from that of the country rock. Material similar in texture and appearance is to be seen in the Goliad sandstone at the base of the Reynosa in South Texas and in similar sandstone occurrences at the base of the Citronelle in East Texas and Louisiana. Inasmuch as similar boulders have been observed throughout a wide area, lying on sur-

faces of formations from Navarro to Sparta in age, it is believed that they represent indurated material developed on an old peneplain, probably basal Pliocene in age.

Reklaw.—The Reklaw is essentially laminated, glauconitic, chocolate, sandy clay. There is a gradual transition from the sand of the Carrizo to glauconitic sands, then glauconitic clays, with no trace of unconformity. Fossils are present from the lowest glauconitic layers through about 45 feet of section. *Venericardia planicostata* casts are present in abundance, especially near the base and at the top of this interval. Exposures of these beds are numerous within a radius of 2 or 3 miles from the village of Kelsey. Especially north and west from the high, a considerable ferruginous clay zone occurs above the fossils. Though no fossils were observed, its general appearance suggests that it should be classified with the Reklaw.

Carrizo.—The Carrizo is not extensively developed in this area. Between lignitic Wilcox shales and the Reklaw, however, there is 15–20 feet of argillaceous, orange-red sand, certainly Claiborne in lithology, which is correlated with the definite Carrizo of the regional outcrops. Though the lithologic break is clear, no conformable contacts with the Wilcox were noted in this area.

Wilcox.—Only about 50 feet of Wilcox sediments are exposed at Kelsey, outcrops having been noted in both Kelsey and Little Cypress valleys on the highest part of the fold. They consist of gray, laminated, non-fossiliferous, slightly micaceous, sandy clays with carbonaceous and lignitic layers. There is a considerable quantity of bentonitic material in the top beds, which is a characteristic occurrence in East Texas. In this area Wilcox shales are differentiated from overlying Reklaw shales by the absence of glauconite and fossils, and the fact that the carbonaceous material of the Wilcox has a sooty black color rather than the smoothly disseminated, waxy, chocolate-brown cast characteristic of the Claiborne.

UNEXPOSED BEDS

EOCENE

Wilcox.—The Wilcox formation is represented by 798–1,030 feet of shallow-water deposits which are predominantly sandy. Beds of lignite, gray lignitic clays, and sands are interstratified. The sands and sandy shales are micaceous and the grains are fine, angular to subangular, clear quartz. Hard sandstone and siltstone concretions are common and are logged as "rocks" or "boulders." The siltstone concretions are calcareous, but some of the sandstone concretions are

wholly siliceous. Lignite, either in beds, thin streaks, or disseminated particles, and boulders are characteristic features of the Wilcox.

Midway.—The Midway formation ranges from 591 to 645 feet in thickness. It is primarily blue and gray clay and shale. Thin beds of calcareous sandy material are present in places and hard siderite concretions are numerous. The Midway is non-calcareous with the exception of the bottom 200 feet, which is distinctly calcareous and contains many fossils. This basal calcareous zone thickens from 25 feet in southwestern Arkansas to almost the full thickness on the outcrop on the west side of the East Texas basin. A small amount of glauconitic sandy shale is generally found at the base of the formation.

GULF SERIES

Navarro.—The Navarro, highest Upper Cretaceous, is 550–600 feet thick in this area. It is made up of fossiliferous gray, calcareous shales and shaly, slightly glauconitic sandstones. For the most part the upper 300 feet are gray clays which are more calcareous, finer and smoother than the overlying Midway. About 300 feet from the top of the formation is a sandy zone, 100–150 feet thick, which is the Nacatoch sand member. There is no clean sand body present, the section being wholly gray, shaly, slightly glauconitic sandstone. In places it is micaceous and contains small amounts of lignite. Below the Nacatoch sand is more gray calcareous shale to the base of the formation.

Taylor.—The Taylor formation is 1,309–1,421 feet thick. It is divided into three parts: Upper Taylor shale, Pecan Gap chalk, and Lower Taylor shale.

The Upper Taylor shale is 180–200 feet thick and consists of gray calcareous shale and marl with hard chalky streaks near the base.

The Pecan Gap chalk, as herein defined, is gray to white, and has a uniform thickness of 400 feet. The bottom 100 feet is broken with gray calcareous shale streaks. The Pecan Gap is easily recognized by the drillers in this area because it is hard and the cuttings make the drilling mud milky.

The Lower Taylor shale varies in thickness from 729 to 800 feet. The upper part is dark gray, slightly calcareous and micaceous shale, becoming sandy and glauconitic with depth. A 70-foot sand body carrying salt water is found 300 feet above the base of the Taylor. This sand is firm, gray, slightly calcareous, and glauconitic. Below the sand, to the base of the Taylor, are shale and sandy shale, slightly calcareous, micaceous, and glauconitic.

Austin.—Forty to 65 feet of hard gray fossiliferous chalk with hard calcareous shale streaks make up the Austin. The base is marked

by a thin pebble conglomerate. The pebbles range in size from ¼ to 1 inch in diameter and are well rounded and predominantly black, and are united by a chalky cementing material.

Eagle Ford.—As defined in this paper the Eagle Ford consists of 65–75 feet of shale and sandy shales lying immediately below the Austin chalk. These sediments are fossiliferous and range from black smooth shales to gray sandy shale. The sandy material is micaceous and commonly contains glauconite and finely disseminated lignite. Finely laminated gray shale and lighter gray sandy shale having a wavy appearance are characteristic.

Woodbine.—The Woodbine, as herein differentiated, has a thickness of 350–456 feet and is made up of sands, sandy shale, and shales, with the sandy material predominating. The sands are gray to greenish gray and range in texture from fine-grained to small pebbles. The sandy members are generally ashy and micaceous and ordinarily chloritic and lignitic. The cleanest, most porous sands are in the bottom 200 feet of the formation. The shales are gray, commonly lignitic, red, green, and purple. The vari-colored shales are the product of oxidation and occur at irregular intervals throughout the section; hence they are of little value in close correlation. The ash and bentonite also range from top to bottom of the formation with the ash ordinarily occurring as cementing material for the sands. Beds and chips of lignite and a few near-shore fossils indicate shallow-water deposition.

COMANCHE SERIES

Washita shale (Del Rio?).—At the top of the Lower Cretaceous is 25–42 feet of hard brownish shale which is thought to be the equivalent of the Del Rio. The shale is slightly calcareous and contains small specks of lignite and numerous mega-fossils. Although elsewhere, as on the Sabine uplift, there is a notable erosion interval between the Gulf and Comanche series, the Woodbine in this locality merges gradually into the Washita shale without evidence of unconformity.

Washita limestone.—This group has not been subdivided into its members. The only well in the area to completely penetrate the Washita, the Amerada Wade No. 1, had 788 feet of section. This is mostly hard white and gray crystalline limestone with a minor amount of shaly limestone and hard gray calcareous shale.

Fredericksburg.—The Amerada Wade No. 1 had 257 feet of hard, pearl gray, finely crystalline limestone and dark gray limy shale which has been determined as Fredericksburg in age.

Trinity.—A Trinity section of 1,186 feet has been penetrated. It

is divided into the Paluxy sand, 343 feet thick, and Upper Glen Rose limestone, 843 feet thick.

The Paluxy sand is chiefly hard, fine-grained, lignitic, white, gray and greenish porous sand. A few thin beds of gray and red shale, very similar to beds in the Woodbine sand, are interbedded with the sand.

The Glen Rose section penetrated by the drill is predominantly hard, gray, crystalline limestone and gray limy shale. There are a few thin bodies of gray, fine-grained, lignitic, micaceous sands and sandy shales and some red, green, and brown shales. From correlation with other wells in the East Texas basin it is believed that the Amerada Wade No. 1 at its total depth of 6,153 feet is about 100 feet above the Glen Rose anhydrite section.

Surface Structure

The Kelsey anticline occupies an area where the Queen City member of the Mount Selman formation should normally crop out in the axis of the East Texas basin. Areally, it is defined by an inlier of Wilcox, surrounded in order by the younger Carrizo, Reklaw, and Queen City beds (Fig. 3). The Wilcox inlier is 15 miles south of the nearest outcrop of similar beds and 20 miles northwest of the nearest Wilcox exposures on Sabine River southwest of Longview (Fig. 2). Southwest of the inlier the Weches outcrop forms a high dissected scarp standing out 200 feet above the Queen City plain. On the south and east, outliers of Weches are found for a distance of several miles. These stand out as high flat-topped mesas having about the same elevation as the regional outcrops on the southwest side of the area. Remnants of Sparta cap the Weches hills and are the youngest beds exposed in this locality.

The area is drained by Kelsey and Little Cypress creeks. Apparently, the former has been diverted somewhat from a normal northeasterly course by the anticlinal folding, its present position forming a considerable curve, convex toward the south (Fig. 4). This may indicate that the south end of the uplift has undergone the more recent movement. The secondary drainage of both creeks is generally dendritic in character.

The Kelsey anticline is a broad, wedge-shaped structure, pointed toward the south (Fig. 4). The major folding occurred along an axis trending N. 20° W., but a subsidiary feature has almost a north-south trend so that the present shape is bilobate at the north end. The evidence suggests that the depression between the lobes overlies a deep-seated downthrown block, but no concrete evidence of faulting is discernible in the surface beds, nor is there subsurface evidence of such

a condition. The two lobes converge just north of the townsite of Kelsey, where the highest structural elevations were found.

An east-west profile through the Kelsey townsite shows that surface beds are uplifted more than 200 feet above their normal position along the strike. There is more than 100 feet of measurable north closure and an additional 50–100 feet may be inferred from the areal distribution of beds. The area directly affected by the uplift of the Kelsey anticline is approximately 150 square miles and its indirect influence extends over an area twice as large. In both these respects it equals or exceeds similar conditions in and around the Van oil field in Van Zandt County.

Subsurface Structure

Pecan Gap.—The structure on top of the Pecan Gap is shown in Figure 5. On this map the axis of folding has a northwest-southeast trend both from wells on the anticline and in surrounding areas. In this respect it resembles somewhat the major surface structural axis. On this horizon the anticline shows 300 feet of closure. There is less control for north dip than in any other direction, but wells in Camp County, north of the area shown on the map, give adequate evidence of the north closure.

The Pecan Gap dips very gently west and northwest across the East Texas oil field into the syncline in central Upshur County, then rises gently to the crest of the Kelsey anticline. There is a very steep dip from the crest of the anticline west and southwest into Wood County. Datum figures on the Pecan Gap in the five wells drilled on the anticline are all higher than on any wells in the East Texas oil field.

Austin chalk.—On the Austin chalk (Fig. 6) the axis of the anticline has a north-south direction resembling the minor surface axis. There is a gentle east dip into the syncline in central Upshur County which is somewhat east of the syncline on the Pecan Gap. A regular but very gentle westward dip is seen on this horizon across the East Texas oil field. The sharp west and southwest dip from the crest of the Kelsey anticline shown on the Pecan Gap structure is also present on the Austin. There are 250 feet of closure and 400 feet of reverse (east) dip on this horizon. Datum figures on the Austin Chalk in all five wells drilled on the Kelsey anticline are higher than in any wells in the East Texas field save a few on the extreme east edge.

Lower Cretaceous.—There is only very scattered control for contours on the Lower Cretaceous outside of the five wells drilled on the anticline. The axis of the structure is due north and south (Fig. 7).

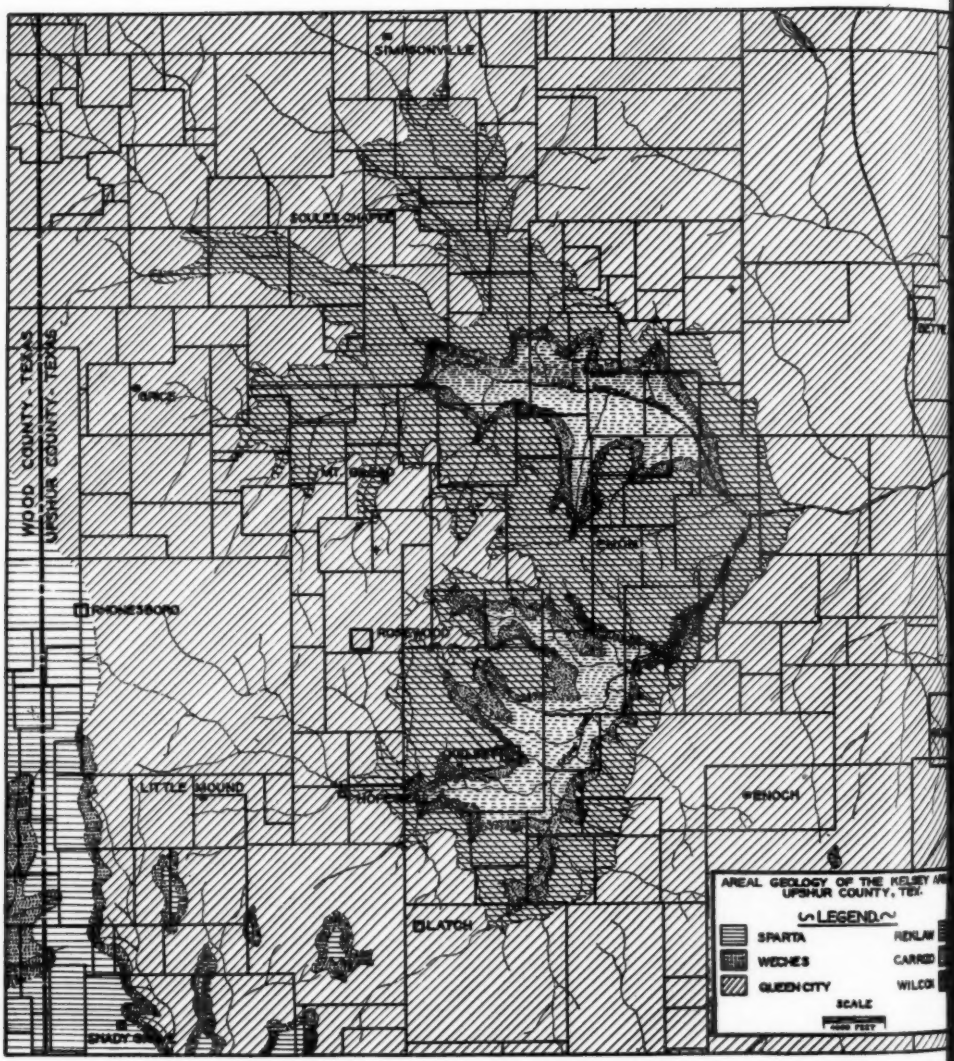


FIG. 3.--Areal geology map of Kelsey anticline, showing inliers of Wilcox, Carrizo, and Reklaw.

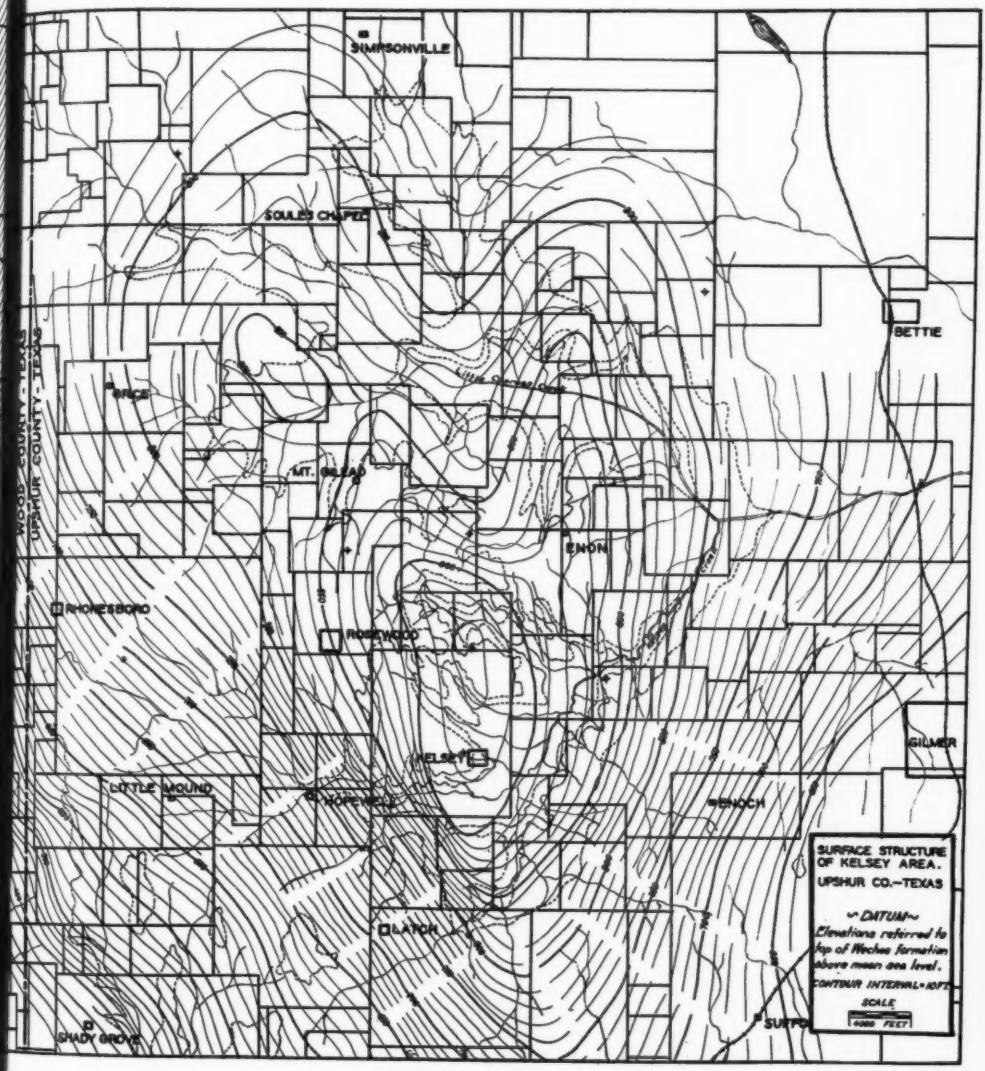
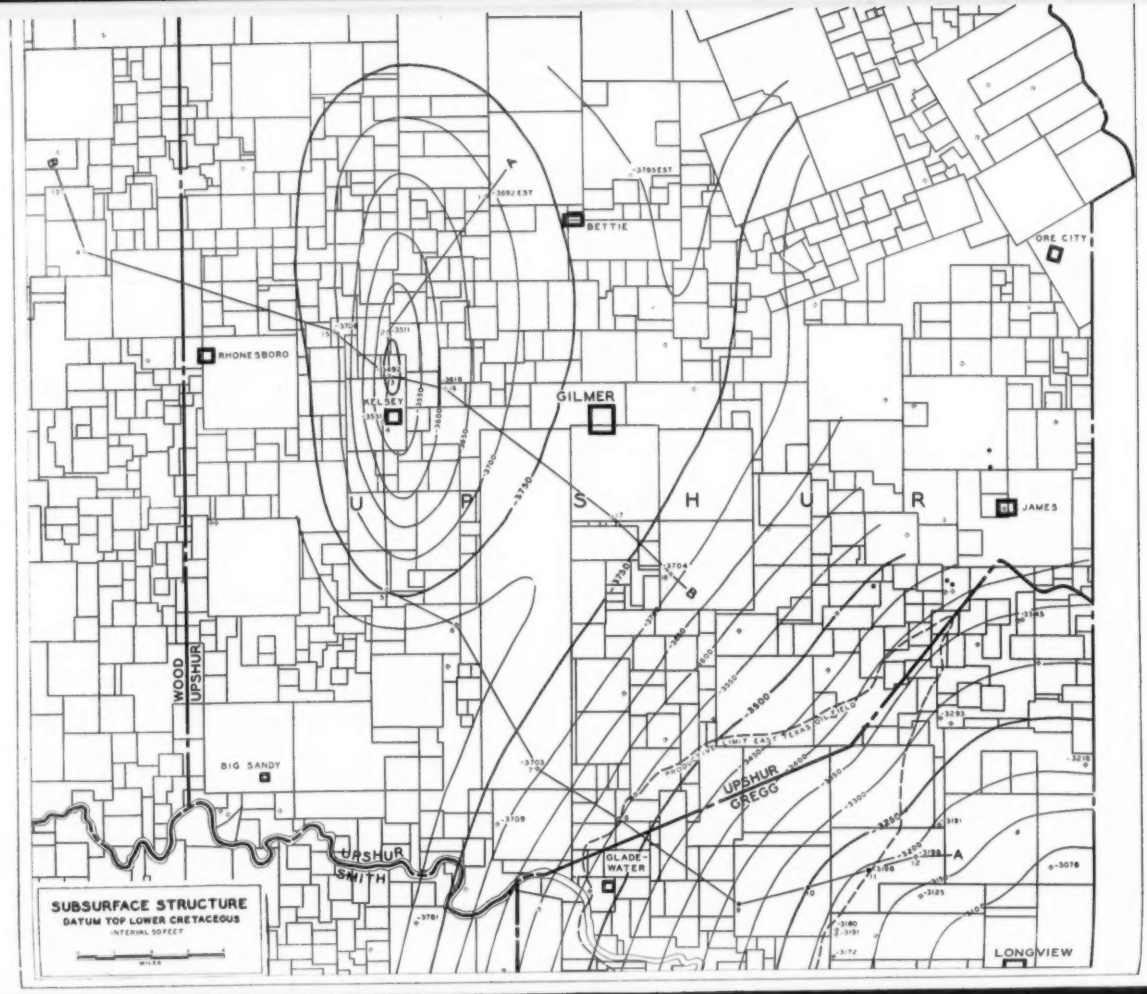


FIG. 4.—Surface structure map of Kelsey anticline, showing bi-lobate character of structure.


BETTIE
ORE CITY
RHONESBORO
KELSEY
GILMER
JAMES
WOOD
UPSHUR
BIG SANDY
UPSHUR
SMITH
UPSHUR
GREGG
GLADE-
WATER
LONGVIEW
SUBSURFACE STRUCTURE
DATUM TOP LOWER CRETACEOUS
INTERVAL 50 FEET

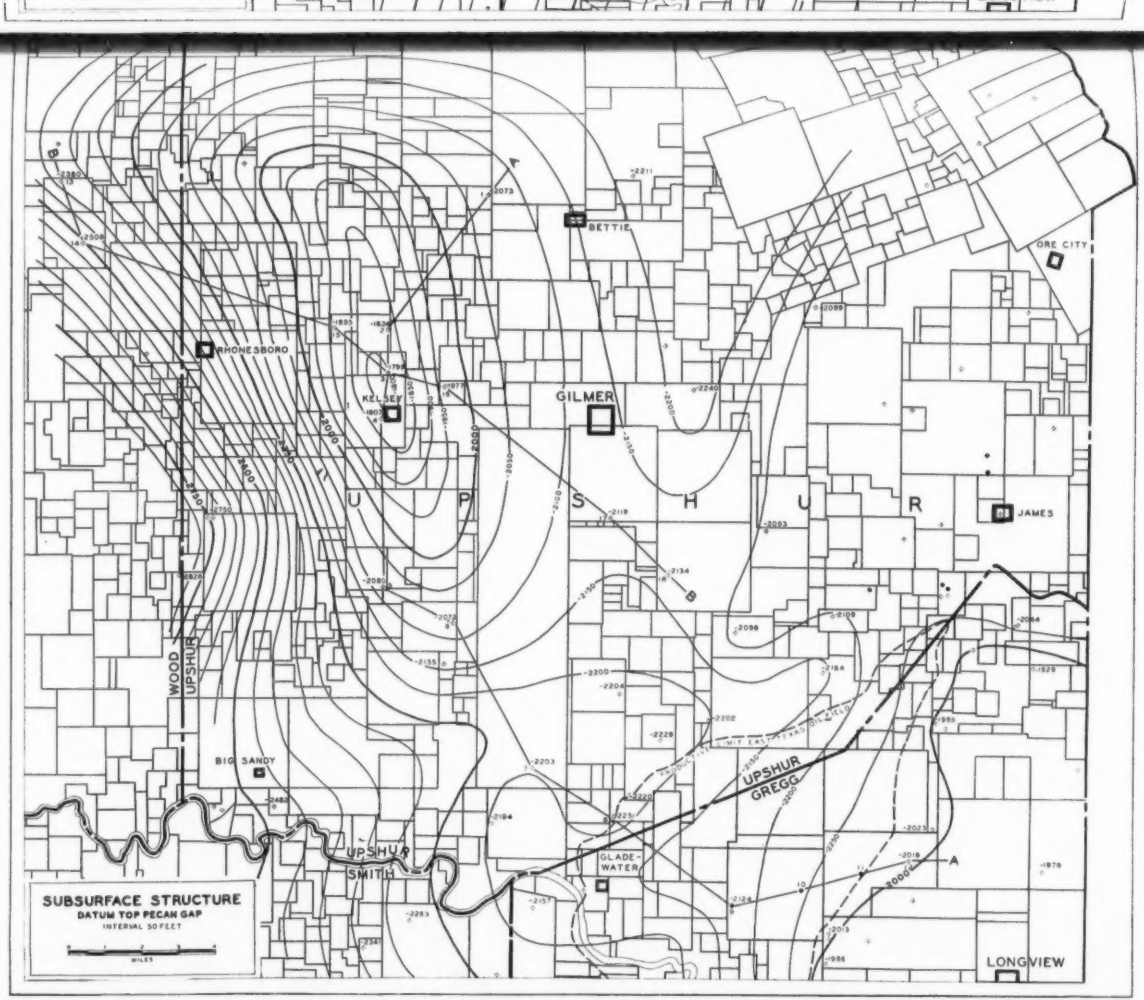


FIG. 6.—Subsurface structure on base of Austin chalk, showing axis of anticline north-south and gentle regular dip over East Texas oil field.

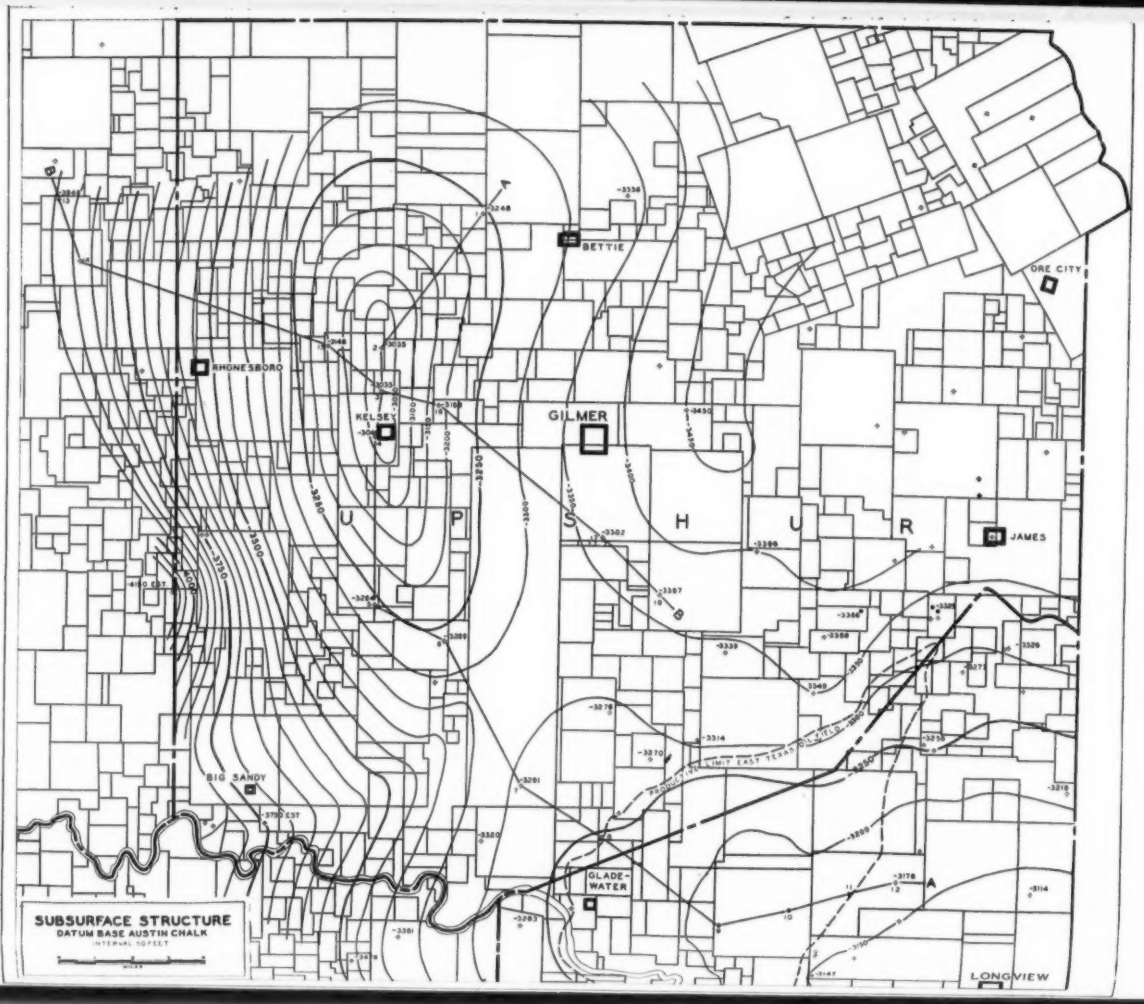

SUBSURFACE STRUCTURE
DATUM BASE AUSTIN CHALK
INTERVAL 50 FEET
RHONESBORO
KELSEY
BETTIE
GILMER
ORE CITY
JAMES
BIG SANDY
GLADE-WATER
LONGVIEW
U P S H U R
A
B

TABLE II

FORMATION DEPTHS AND THICKNESSES, KELSEY ANTICLINE

Formation	*Amerada Wade No. 1 Elev. 430 Feet Starts 12 Feet Above Base Reklaw*			*Evans Bell No. 1 Elev. 413 Feet Starts 4 Feet Below Base Reklaw*			*Potter Irons No. 1 Elev. 431 Feet Starts 60 Feet Above Base Reklaw*			*Pilot Ray No. 1 Elev. 403 Feet Starts 40 Feet Above Base Reklaw*			*Mannus & Snuggs Pool No. 1 Elev. 465 Feet Starts 100 Feet Above Base Reklaw*		
	A Uniform Thickness of 20 feet is Assumed for Carrizo														
	Top	*Base*	*Thickness Feet*	*Top*	*Base*	*Thickness Feet*	*Top*	*Base*	*Thickness Feet*	*Top*	*Base*	*Thickness Feet*	*Top*	*Base*	*Thickness Feet*
Wilcox	32–	830	798^{mi}	16–	820	804	80–	909	829	60–	1,030	970^{m}	120–	940	820
Midway	830–	1,440	610	820–	1,430	610	909–	1,500	591^{mi}	1,030–	1,650	620	940–	1,585	645^{m}
Navarro	1,440–	2,040	600^{m}	1,430–	2,025	595	1,500–	2,074	574	1,650–	2,200	550^{mi}	1,585–	2,156	571
Upper Taylor shale	2,040–	2,229	189	2,025–	2,220	195	2,074–	2,255	181	2,200–	2,380	180^{mi}	2,156–	2,360	204^{m}
Pecan Gap chalk	2,229–	2,650	421^{m}	2,220–	2,640	420	2,255–	2,671	416	2,380–	2,800	420	2,360–	2,760	400^{mi}
Lower Taylor shale	2,650–	3,405	755	2,640–	3,395	755	2,671–	3,400	729^{mi}	2,800–	3,545	745	2,760–	3,552	792^{m}
Austin	3,405–	3,461	56	3,395–	3,459	64^{m}	3,400–	3,461	61	3,545–	3,586	41^{mi}	3,552–	3,613	61
Eagle Ford	3,461–	3,532	71	3,459–	3,525	66^{mi}	3,461–	3,535	74^{m}	3,586–	3,654	68	3,613–	3,684	71
Woodbine	3,532–	3,882	350	3,525–	3,902	377	3,535–	3,916	381	3,654–	3,989	335^{mi}	3,684–	4,140	456^{m}
Washita shale	3,882–	3,922	40	3,902–	3,944	42^{m}	3,916–	3,941	25^{mi}	3,989–	4,021	32	4,140–	4,171	31
Washita limestone	3,922–	4,710	788	3,944–	3,946 TD	2+	3,941–	3,942 TD	1+	4,021–	4,028 TD	7+	4,171–	4,182 TD	11+
Fredericksburg	4,710–	4,967	257												
Paluxy	4,967–	5,310	343												
Glen Rose	5,310–	6,153 TD	843+												

m—Maximum thickness.
mi—Minimum thickness

West dip from the axis is steeper than in the Pecan Gap and Austin chalk. Present available data show 250 feet of closure, but more will probably be found with additional control in the syncline through central Upshur County. Although data are not available to show accelerated west and southwest dip from the crest of the structure, it is believed logical to assume even greater dip than is present on the upper horizons. A very regular northwest dip is present in the Lower Cretaceous across the East Texas oil field at more than twice the rate of the dip on the Austin chalk. Lower Cretaceous datum figures in the wells drilled on the Kelsey anticline are all lower than in any wells in the East Texas field, save at the extreme northwest edge. This change is entirely due to the greater thickness of the Eagle Ford and Woodbine on the Kelsey structure as compared with the productive area.

TABLE III

LIST OF WELLS USED IN CROSS SECTIONS A-A (FIG. 8, 8A, 8B)

1. Arcadia Refg. Co., P. S. Johnson No. 1, J. H. Mallory Survey, Upshur County
2. Gillett, Tarr & Potter D. A. Irons No. 1, D. B. Lucas Survey, Upshur County
3. Amerada Petroleum Corp., C. K. Wade No. 1, J. H. Fields Survey, Upshur County
4. J. P. Evans Mrs. S. A. Bell *et al.* No. 1, Wm. McFadden Survey, Upshur County
5. Sorrels & Duffy J. W. Wooden No. 1, Isham Williams Survey, Upshur County
6. Wood & Nelson H. S. Coslett No. 1, B. F. Howard Survey, Upshur County
7. Penn Oil Gauge No. 1, J. B. Davenport Survey, Upshur County
8. Eastland Oil O. M. Victory No. 1, E. A. J. Evans Survey, Upshur County
9. Shell R. I. Bassham *et al.* No. 1, Wm. H. Castleberry Survey, Gregg County
10. Simms & Stanolind L. E. Persons *et al.* No. 3, Wm. H. Castleberry Survey, Gregg County
11. Tidal F. K. Lathrop No. 1, Wm. Robinson Survey, Gregg County
12. Tidal A. B. Castleberry No. 1, Wm. Robinson Survey, Gregg County

GEOLOGIC HISTORY

UPSHUR COUNTY

At the close of Lower Cretaceous times, Upshur County had a uniform westward tilting in connection with the rise of the Sabine uplift. This movement involved little or no erosion since Washita shales are everywhere preserved below the Woodbine. This tilting movement continued through Woodbine and Eagle Ford deposition, forming a wedge of sediments with increasing thickness from east to west (Figs. 8B, 9B). This tilting was abruptly terminated at the beginning of Austin time when a thin layer of gravel conglomerate was uniformly deposited over a wide area. This was followed by submergence, during which a uniform thickness of Austin chalk was deposited. During early Taylor times, westward tilting was again resumed (Figs. 8A, 9A) on a much smaller scale than previously, and probably continued with minor interruptions through Cretaceous and Tertiary deposition to Wilcox time, when differential movement at Kelsey interrupted the regional uniformity of deposition (Figs. 8, 9). Pecan Gap chalk seems

to reverse the normal process and thins from east to west (Fig. 9). This, however, is believed to represent variation in depositional conditions since the total thickness of Taylor beds, of which the Pecan Gap is a member, normally increases westward.

TABLE IV

LIST OF WELLS USED IN CROSS SECTIONS B-B (FIG. 9, 9A, 9B)

13. F. B. Parriott Stuart No. 1, M. H. Ussery Survey, Wood County
14. Sinclair-Prairie & Replogle Mary Saner No. 1, J. M. Candler Survey, Wood County
15. Mannus & Snuggs G. C. Pool No. 1, S. J. Pounds (E) Survey, Upshur County
3. Amerada Petroleum Corp. C. K. Wade No. 1, J. H. Fields Survey, Upshur County
16. Pilot & Snebold J. G. Ray *et al.* No. 1, A. H. Wood Survey, Upshur County
17. Home Oil Mrs. F. D. Futtrell No. 1, A. Lumbrera Survey, Upshur County
18. Scott & Ashford D. Douphrate No. 1, Torres Survey, Upshur County

KELSEY ANTICLINE

At the close of Lower Cretaceous time, concurrently with the westward tilting of Upshur County, a slight differential movement occurred at Kelsey, along a north-south line, which elevated the Lower Cretaceous at Amerada Wade No. 1 above its position at Gillett, Tarr, and Potter's Irons No. 1 and J. B. Evans' Bell No. 1, (Fig. 8B). This movement did not affect the entire present anticlinal area, since the east-west section (Fig. 9B) shows normal westward thickening of the Woodbine and Eagle Ford.

The Kelsey area had normal deposition in the Austin, but in Taylor time there was a slight differential warping, allowing a thinner section to be deposited under Gillett, Tarr, and Potter's Irons No. 1 than under any of the other four wells on the anticline. Deposition again was normal, giving westward thickening of beds across the anticline until Wilcox time. Distinct differential warping, which probably continued through Wilcox deposition, gave a thickness of 1,030 feet of this formation in the Pilot Ray No. 1 as compared with 830 feet in Amerada Wade No. 1. This movement probably affected the entire anticline and produced, for the first time during depositional history, a closed structure. Insufficient data are available to determine whether the differential movement which started in the Wilcox continued through the remainder of Claiborne time. Subsequent to Sparta deposition, notable broad warping, affecting the western half of Upshur County, arched the entire geologic section in the form it now has and produced the Kelsey anticline. This movement probably again coincided with the final arching of the Sabine uplift.

RELATION OF SURFACE TO SUBSURFACE STRUCTURE

There is a close coincidence between the highest surface point and the highest subsurface point on the Kelsey structure. Amerada Wade

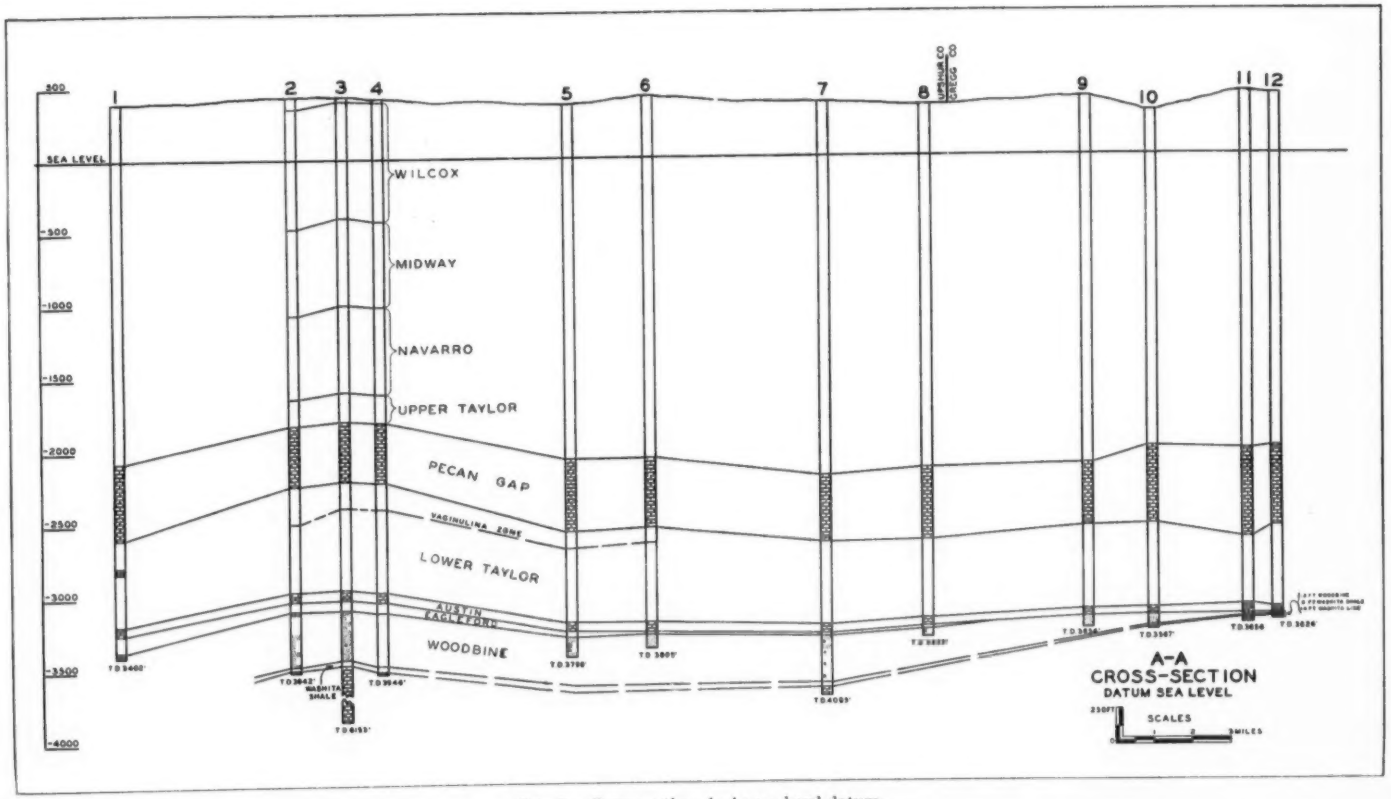


FIG. 8.—Cross section *A*–*A*′; sea-level datum.

FIG. 8.—Cross section *A–A'*; sea-level datum.

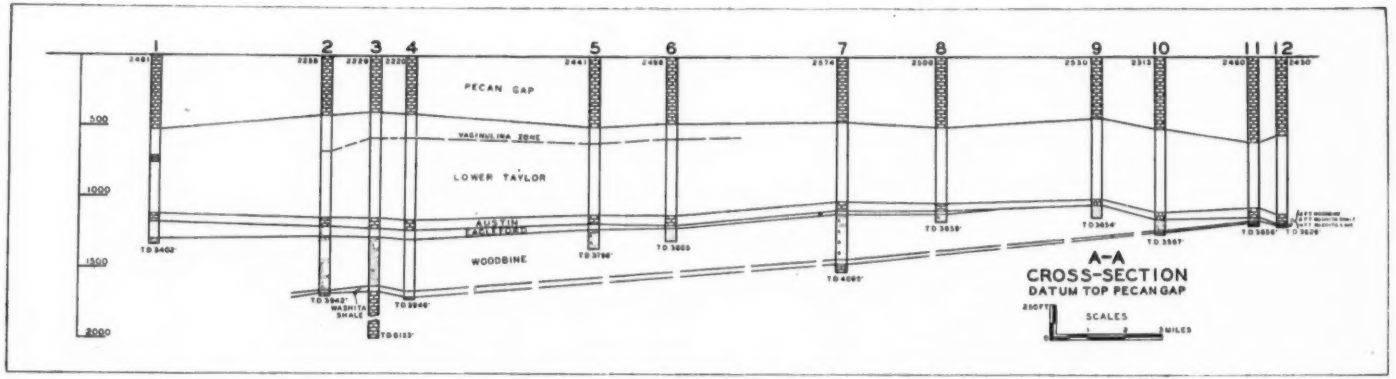


FIG. 8A.—Cross section *A–A'*; datum on top of Pecan Gap.

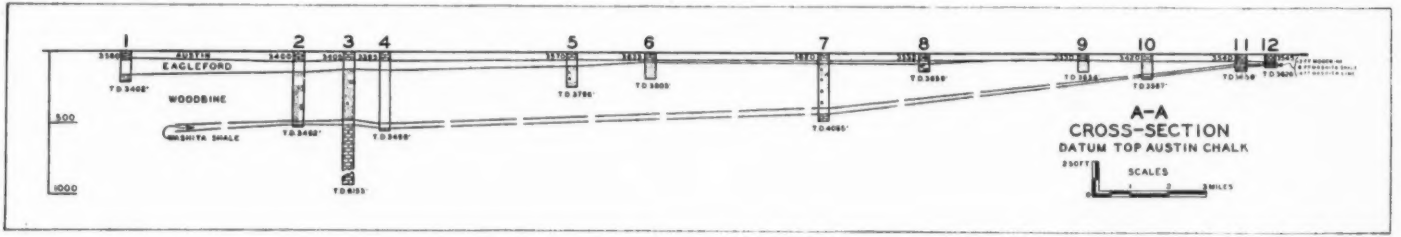
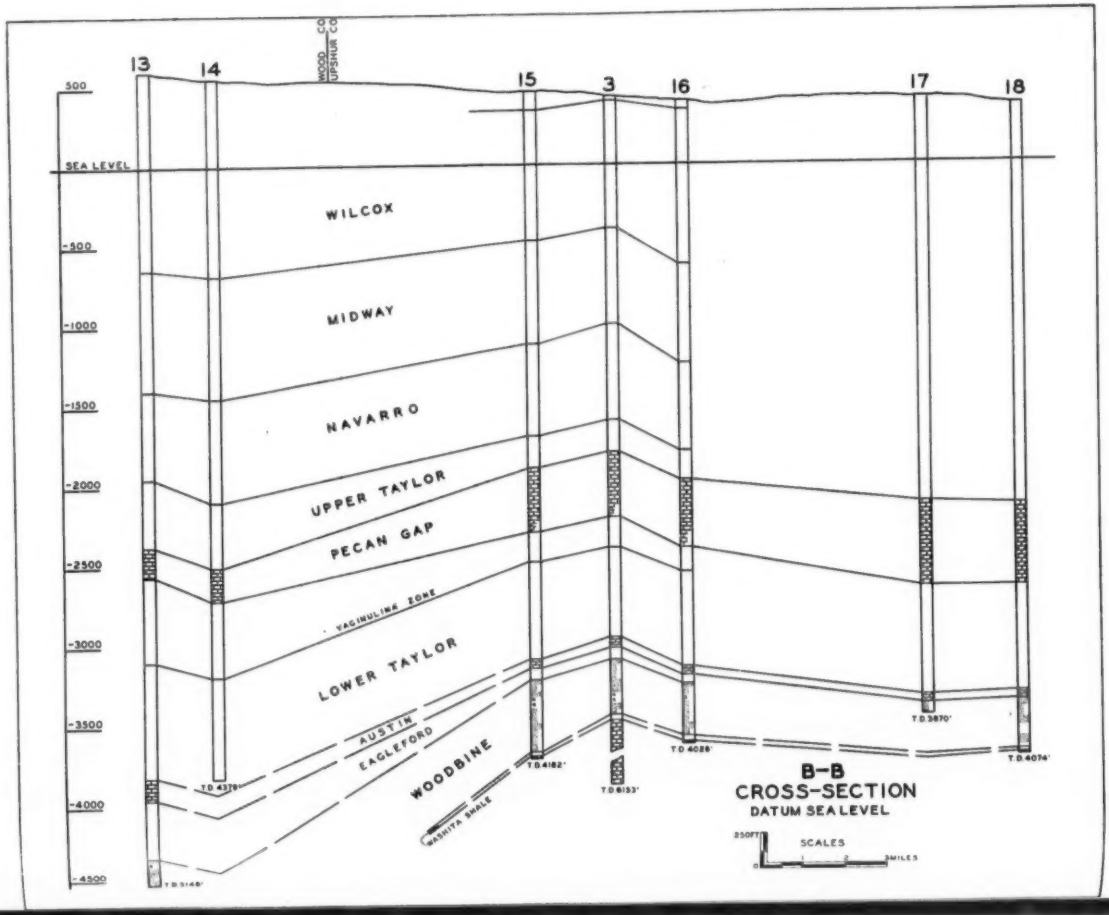


FIG. 8B.—Cross section *A–A'*; datum on top of Austin chalk.


13
14
WOOD CO.
UPSHUR CO.
15
3
16
17
18
500
SEA LEVEL
-500
-1000
-1500
-2000
-2500
-3000
-3500
-4000
-4500
WILCOX
MIDWAY
NAVARRO
UPPER TAYLOR
PECAN GAP
VAGINULINA ZONE
LOWER TAYLOR
AUSTIN
EAGLEFORD
WOODBINE
WASHITA SHALE
T.D. 4378'
T.D. 5148'
T.D. 4182'
T.D. 6153'
T.D. 4028'
T.D. 3870'
T.D. 4074'
B-B
CROSS-SECTION
DATUM SEA LEVEL
250FT
SCALES
0
1
2
3 MILES

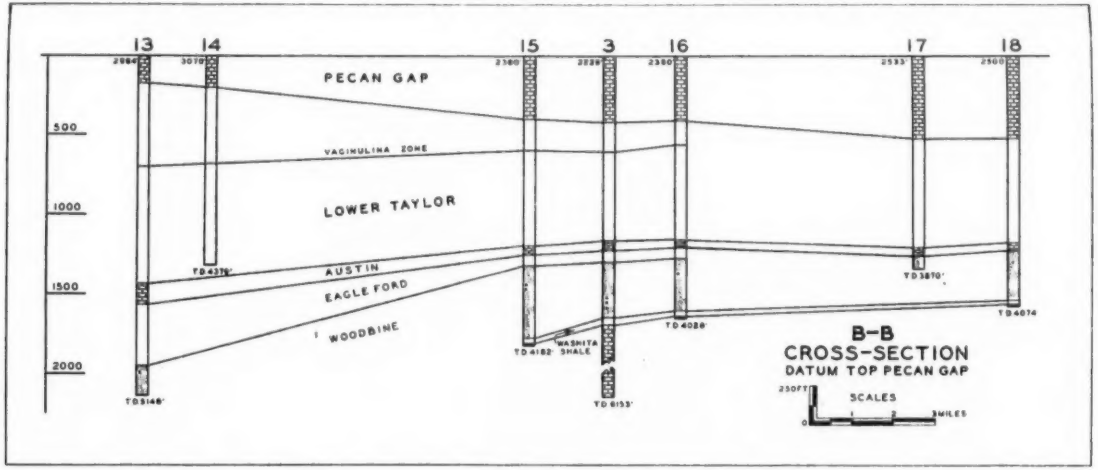


FIG. 9A.—Cross section *B–B;* datum on top of Pecan Gap.

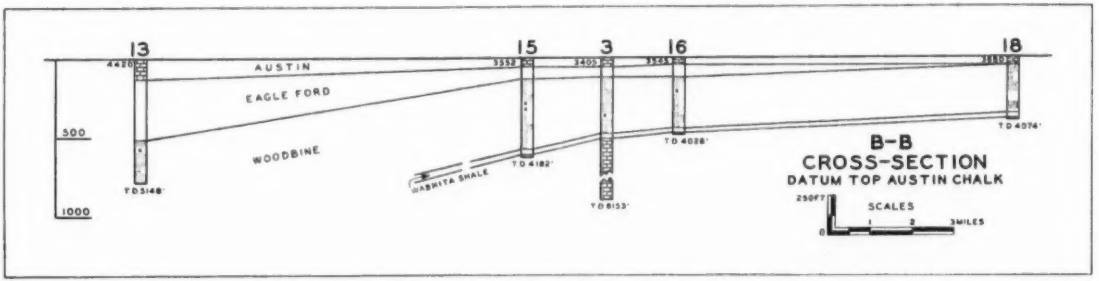


FIG. 9B.—Cross section *B–B;* datum on top of Austin chalk.

No. 1 occupies this point on both surface and subsurface structure maps. This close relationship is not found when comparing the other four wells drilled. The Gillett, Tarr, and Potter Irons No. 1 and the Manus and Snuggs Pool No. 1 are on the same surface contour, but there is 196 feet of west dip on top of the Washita limestone. On the surface there is 55 feet of north dip from Amerada Wade No. 1 to Gillett, Tarr, and Potter's Irons No. 1, though on the Washita limestone there is only 6 feet. In general, the direction of dip is the same on surface and subsurface, but may be decreased or accentuated on the lower horizons.

Subsurface evidence indicates a north-south axis with accentuated westward dip and without the bi-lobate character present on the surface. This discrepancy is accounted for in part by a normal thicker section extending from east to west, and in part by differential deposition of Tertiary beds, resulting in a thicker section on the flanks of the structure than on the crest.

There is surface evidence for 100–200 feet of closure; on subsurface beds there is 300–400 feet of closure. As noted under Subsurface Structure, there is less closure on the Austin and Lower Cretaceous than on the Pecan Gap. This is again evidence that there was little or no folding at Kelsey until after Cretaceous time. On the Van structure, in Van Zandt County, there is no measurable closure on equivalent surface beds (Reklaw-Carrizo), but closure may be present in the Wilcox. Subsurface structure on the Lower Cretaceous shows closure of 2,000 feet or more. The Van structure had differential movement giving a thinned section at least from Woodbine on through Upper Cretaceous and probably Tertiary time.

Summary and Conclusions

The presence of an anticline having been demonstrated at the surface, marked by areal and structural evidence with more than 100 feet of closure, and this evidence having been substantiated by subsurface structure with more than 300 feet of closure, the question arises as to why this pronounced structure contained no oil accumulation in the Woodbine sand.

Oil accumulation in the Woodbine sand occurs in the following types of structure.

1. Closed structure against a fault (Mexia-Powell)
2. Closed structure with subsidiary faulting (Van)
3. Closed structure against a fault associated with a salt dome (Boggy Creek)
4. Closed structure due to sand pinching-out up the dip (East Texas field)

All these types have one feature in common, namely, closed structure. This feature is shared by the Kelsey anticline. Three of the types have

faulting associated with accumulation; no such condition can be demonstrated at Kelsey. There is also adequate evidence that no "pinching sand" condition is present at Kelsey.

A factor which all four types of producing structures have in common and which is not in evidence from the foregoing classification, is closed structure forming a trap in Cretaceous time. As has been demonstrated under Geologic History, Kelsey was not a closed structural trap until Wilcox time. Based on our present knowledge, this appears to be the most logical reason for the lack of oil accumulation on the Kelsey anticline in the Woodbine and other members of the Gulf series. Several known productive horizons, including the gas "pay" of the Rodessa and Bethany fields, at the base of the Glen Rose anhydrite section, have not been reached by any well drilled thus far and their productive possibilities remain unknown.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), PP. 680-693, 5 FIGS.

RESULTS OF STRUCTURAL RESEARCH WORK IN BEARTOOTH-BIGHORN REGION, MONTANA AND WYOMING[1]

W. H. BUCHER,[2] R. T. CHAMBERLIN,[3] and W. T. THOM, JR.[4]
Ohio, Illinois, and New Jersey

ABSTRACT

Recent structural studies have confirmed or established the following facts regarding the tectonics of the Beartooth-Bighorn region: (1) the Big Horn Basin is featured by peripheral folds (characteristically asymmetrical), apparently due to differential movement on basement faults; (2) the Pryor Mountains consist of four crustal blocks, each uplifted at the northeast corner, and bounded on the north and east by faults merging into monoclines; (3) there are local overthrusts on both the eastern and western sides of the Bighorns; (4) there is southward overthrusting south of the Wind River Canyon; (5) there are eastward, northward (and southward), and southwestward thrusts around the Beartooth Range.

INTRODUCTION

The Beartooth-Bighorn region of Montana and Wyoming was chosen as a field for structural research because of the unusual opportunities it seemed to offer for a solution of fundamental problems of mountain building and of crustal deformation. Convergent and coördinated attacks have been made upon these central problems, using, respectively, structural, stratigraphic, paleontologic, petrologic, physiographic, and geophysical methods, and, though the study is by no means completed, many interesting and significant facts and relationships have been disclosed. Some of the more important of these findings are summarized in this paper.

LOCATION OF AREA

The Beartooth-Bighorn area, shown on the accompanying key map (Fig. 1), embraces the Big Horn Basin area of northwestern Wyoming and south-central Montana, its encircling uplifts, and some contiguous territories. It includes the unusual volcanic area within

[1] Read before the Association at the Houston meeting, March 25, 1933. Manuscript received, March 3, 1933.

[2] Department of geology and geography, University of Cincinnati.

[3] Department of geology, University of Chicago.

[4] Department of geology, Princeton University, Walter B. Sharp Research Fellow 1931–32) of The Rice Institute.

and adjacent to Yellowstone Park, and it lies just south of the fairly definite line separating the elongate, continuously overthrust Front ranges of the Northern Rockies, from the "range and basin" region of the Central Rockies.

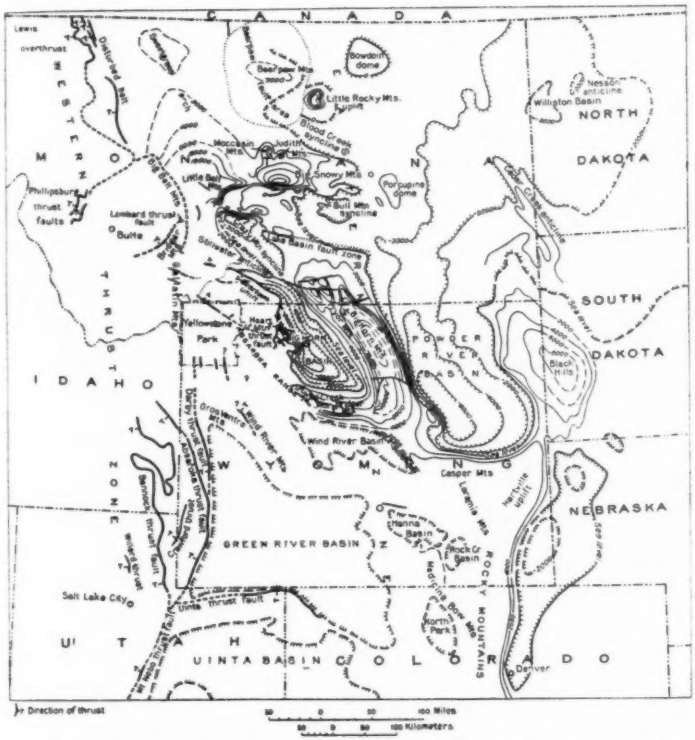


FIG. 1.—Sketch map showing structural setting of Yellowstone-Beartooth-Bighorn region. Contours show approximate altitude of Dakota or Cat Creek sandstone. Adapted from Plate 3 of *Sixteenth International Geological Congress Guidebook 24.*

ACKNOWLEDGMENTS

The studies yielding the results to be described by us have, in the nature of the case, been founded on the great amount of excellent work which has been done in the region by the Federal and State Geological Surveys, by members of The American Association of Petroleum Geologists, and by other geologists, and they have been executed by a group of individuals voluntarily collaborating in the

conduct of the work because of their interest in the problems under attack. Among those participating are men who are members of one or more of the following organizations: The American Association of Petroleum Geologists; The Geological Society of America; the National Research Council Committee on Studies in Petroleum Geology; the National Research Council Tectonics Committee; and the American Geophysical Union. Most of the participants are also members of university or college geological faculties, and field operations have been based on the Princeton Geological Research Camp near Red Lodge, Montana.

Hearty and most helpful coöperation has been received by this research group from the universities of Montana and Wyoming; from the Montana Bureau of Mines and Geology; from the Wyoming Geological Survey; from the International Summer School of Geology and Natural Resources; from the Northern Pacific Railway; and from the United States Geological Survey; Army Air Corps; Coast and Geodetic Survey; National Park Service; Forest Service; and various county and municipal officials and civic groups.

STRATIGRAPHIC GEOLOGY

The general stratigraphy of the Beartooth-Bighorn region is so well known as to render a detailed discussion of it superfluous for present purposes, and the sequence and salient features of the formations present will merely be summarized in Table I.

As shown by Table I, the region is characterized by a relatively complete stratigraphic sequence, comprised of Paleozoic limestones and shales deposited in widespread, oscillating epicontinental seas; Mesozoic and Paleocene shales and sandstones of marine to continental origin, revealing by thickness variations the inception of Laramide deformation in Upper Cretaceous time; and continental Tertiary and Quaternary basin and flood-plain deposits closely related in origin and geographic distribution to the present uplifts and basins of the region.

STRUCTURAL GEOLOGY

As the familiar geologic map of Wyoming reveals, the elongate structural depression of the Big Horn Basin is bordered on the northeast and east by the Pryor and Bighorn mountain uplifts; on the south and southwest by the Bridger and Owl Creek ranges: and on the northwest by the Beartooth uplift (Fig. 1). It has been customary to consider the deformational features both of the Big Horn Basin and of its included and contiguous uplifts as predominantly the prod-

ucts of normal folding under tangential compression. This belief is subject to a number of important modifications, as is revealed by the following descriptions of the structure of particular tectonic features of this region, and by Figure 2.

Pryor Mountains.—The Pryor Mountains are structurally an elongate uplift, plunging both north and south, in which the central and higher portion is divided into four segments, bounded by subsurface faults merging into surface monoclinal folds. Each segment has been uplifted at its northeastern corner (Fig. 1) and the most highly elevated block (the southeastern segment) gives evidence of incipient northeastern thrusting at its northeastern corner.[1]

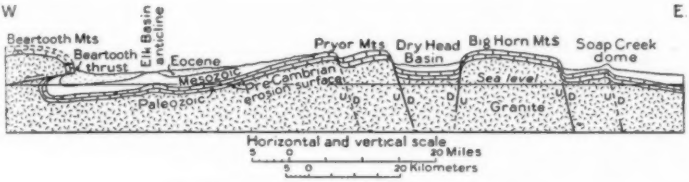


FIG. 2.—Structure section across Beartooth, Pryor, and Bighorn mountains. *Sixteenth International Geological Congress Guidebook 24*, Figure 11, p. 50.

Bighorn Mountains.—The Bighorn Mountains are a compound, elongate uplift consisting of individual horst-like or "trap-door" features in the basement crystalline rocks, over which the mantling sediments are passively draped in "flats" and monoclines (Figs. 2, 3, and 4). At the north end of the range, the structure is horst-like, the flanks of the range being formed by 70°–90° monoclines with nearly flat strata between. Near the Montana-Wyoming line, an east-west monocline apparently continues the Black Gulch fault across the range, and south of this line the west flank of the range is characterized by strong uplift, striking monoclines, and appreciable westward overthrusting of this flank, whereas moderate eastward dips prevail along the eastern side of the range. Farther south this situation is reversed, dips along the western flanks being fairly gentle, the crest of the uplift lying near the east border of the mountains, and local eastward thrusting and striking monoclines being conspicuous on the east flank midway between Sheridan and Buffalo.

East of Tensleep, the crest of the range is crossed by an east-west fault, and south of this fracture the uplift appears to consist of several rotated basement blocks, each uplifted along its western edge, with

[1] Donald L. Blackstone, personal communication.

TABLE I

SEDIMENTARY FORMATIONS EXPOSED IN BEARTOOTH-BIGHORN REGION‡
(Adapted from Table by John G. Bartram, Stanolind Oil and Gas Company)

	Age	Formation		Character	Origin
		Billings Area	*Cody Area with Thickness in Feet*		
Tertiary				Andesitic tuffs and flows	Deposits that spread from the Yellowstone Park volcanic center
	Eocene*		Wind River and Wasatch (1,000)	Red and drab clay, buff and white sandstones and gravel beds. Strong angular unconformity near basin margins	Flood-plain and stream deposits formed after a period of major deformation. Contains mammalian vertebrates, leaves and invertebrate fresh-water fossils
	Paleocene†	Fort Union	Fort Union (3,600)	Buff and white sandstones, with drab and green clay; some gravel beds and seams of coals. Some angular unconformity at base near basin margins	Fresh-water sediments deposited in flood plains, swamps, etc.
		Lance*†	Lance*† (700)	White and buff sandstones with large concretions and yellow, green, and gray clay	Fresh-water sandstones and clays locally, with abundant dinosaur remains and fossil leaves
		Lennep Bearpaw	Meeteetse (1,100)	Soft gray and brown shale, with gray and buff sandstones and some coal	Marine shale rapidly grading to sandy non-marine beds farther west
		Judith River	Mesaverde (850)	Prominent gray and white sandstones with gray and brown shale and coal	Sandstone and coal series, partly marine, partly brackish water,

* As prepared by Bartram the Mesozoic-Tertiary boundary was placed beneath the Lance formation.

† The U. S. Geological Survey classifies the Fort Union formation as Eocene and the Lance formation as Tertiary(?).

‡ R. M. Field and others, "Yellowstone-Beartooth-Big Horn Region," *XVI International Geological Congress Guidebook 2*, U. S. Govt. Printing Office (1932), p. 2.

Mesozoic	Upper Cretaceous	Judith River	Mesaverde (850)	Prominent gray and white sandstones with gray and brown shale and coal beds near base	Sandstone and coal series, partly marine, partly brackish water. Source in the west, thins eastward
		Claggett			
		Eagle	Cody (2,200)	Gray and black marine shale, with Eagle sandstone near top	Marine beds deposited not far from western shore line
		Telegraph Creek			
		Niobrara			
		Carlile			
		Frontier	Frontier (550)	Two or more beds of gray and buff sandstone with gray and brown shale and some bentonite	Wedges from a thicker sandstone formation the west; thin and disappear eastward
		Mowry	Mowry (200)	Hard gray siliceous shale with fish scales. Breaks in thin rectangular fragments	Peculiar character probably due to admixed volcanic material
		Thermopolis	Thermopolis (450)	Gray to black shale with one sandstone (the "Muddy") and several bentonite beds	Marine shale and altered pyroclastics derixed from west
		Cloverly	Cloverly (128)	Upper hard sandstone, variegated shale, and lower conglomeratic sandstone, containing abundant pebbles of black chert	Upper bed of Cloverly is basal sandstone of invading Interior Cretaceous sea
	Lower Cretaceous	Morrison	Morrison (400)	Gray to reddish or purplish shale, white sandstones and one or more thin gray limestones	Fresh-water material that in places contains dinosaur bones and gastroliths
	Jurassic	Sundance	Sundance (575)	Blue-green shale, yellow and green sandstones, fossiliferous sandy limestone, reddish shale, and some gypsum	Deposited in a Jurassic sea that lay mostly north and west of this area. Sandstones increase to south
	Triassic	Chugwater	Chugwater (975)	Bright red sandy shale and shaly sandstone. Some gypsum beds and thin limestones	The Red Beds contain few fossils. Evenly deposited material that grades into non-red marine deposits farther west. Disappears on north

TABLE I (*Continued*)

	Age	Formation: Billings Area		Formation: Cody Area with Thickness in Feet	Character	Origin
Paleozoic	Permian	Bighorn Mts.	Beartooth Reg.	Embar (150)	Hard, cherty limestone, and one interbedded sandstone	Permian sea was largely on west and limestones grade rapidly into red shales and gypsum on east
		Embar	Phosphoria			
	Pennsylvanian	Tensleep	Tensleep	Tensleep (180)	Quartzitic sandstone, calcareous in some layers	Very widespread cross-bedded marine and aeolian sandstone that covers large areas in the Rocky Mountains
		Amsden	Amsden and Quadrant (probably)	Amsden (200)	Cherty and sandy limestone, red and purple shale, and purple sandstone	A catch-all formation that probably contains marine beds representative of several Pennsylvanian and perhaps Upper Mississippian formations
	Mississippian	Madison	Madison	Madison (1,200)	Buff, white or grayish limestone with some chert	Deposited over most of the Rocky Mountain area
	Devonian		Three Forks		Gray shale and limestone	Present in western Montana and absent in eastern Wyoming and Montana
			Jefferson		Brownish buff, more or less crystalline, thin-bedded limestone	
	Ordovician	Bighorn	Bighorn	Bighorn (350)	Hard, massive, light-colored dolomite and limestone	Marine limestone, difficult to distinguish from the Madison. Characteristically shows pitted weathering
	Cambrian	Deadwood	Gallatin Gros Ventre Flathead	Deadwood (1,150)	Light-colored limestone, green and red shales, and a basal arkosic sandstone or quartzite	Deposited during progressive eastward marine transgression during Middle and Upper Cambrian time
	Pre-Cambrian	Granite		Granite, schist, etc.		

probable westward thrusting along the major fault, which advances to the west flank of the range near Big Trails and Nowood.

Bridger-Owl Creek Range.—Information regarding the structure of the Bridger-Owl Creek zone of uplift is as yet limited to that available from reconnaissance in the Wind River Canyon, south of Thermopolis, and from Darton's maps and reports based upon his early surveys. It is known, however, that east of the Wind River Canyon the range is strongly asymmetrical, with a steep south flank, and a long, gentle north flank, and that a considerable southward overthrust exists at the south portal of the Wind River Canyon. West of the canyon, the exposed crystalline core of the Owl Creek Mountains seems to be bounded by outward overthrusts on both its northeastern and southwestern flanks.

Beartooth Mountain-Rattlesnake Mountain uplift.—The Beartooth Mountain uplift is an asymmetrical, elongate uplift, the crest line of which lies near its northeastern margin and plunges rapidly southeastward to the termination of the range south of the Clark Fork Canyon. From this canyon northward and northwestward to the Rosebud-Boulder divide, the granitic core of the range is overthrust eastward and northeastward at low angles upon the Mesozoic and Paleocene formations. In the Boulder drainage there is a suggestion of a reversal in the direction of thrusting, and in the Yellowstone valley just south of Livingston a window of Cretaceous rocks (Cloverly formation) shows beneath the Cambrian and demonstrates that a southward thrust of several miles has occurred here. From this locality to the Devil's Slide, northwest of Gardiner, the structure has not yet been ascertained, but at the Devil's Slide it can be seen that the Beartooth block has here been overthrust southwestward on a high-angle fault, this fault being traceable southeastward for a dozen miles or more and entering Yellowstone Park a mile or so east of Gardiner. Exposures of the crystalline and Paleozoic rocks which occur southeast of this locality are consistent with the idea that the basement fault underlying the steep southwest limb of the Rattlesnake uplift near Cody (Fig. 3) is essentially a prolongation of the high-angle thrust of the Devil's Slide-Gardiner fault zone. The Rattlesnake Mountain uplift is, moreover, notable because it has been overridden by an overthrust sheet of Paleozoic limestones, remnants of which remain as the cappings of Heart Mountain, Sheep Mountain, and other near-by topographic features.

Big Horn Basin.—The Big Horn Basin is a partly topographic and partly structural depression. It is evidently a compound feature, structurally, and the full extent of its structural complexity is as yet

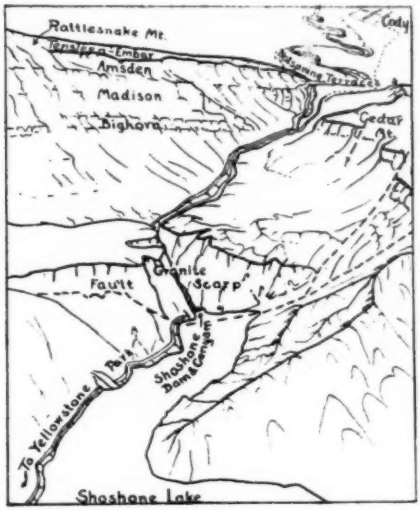


FIG. 3.—View eastward through canyon cut by Shoshone River across Rattlesnake Mountain "anticline."

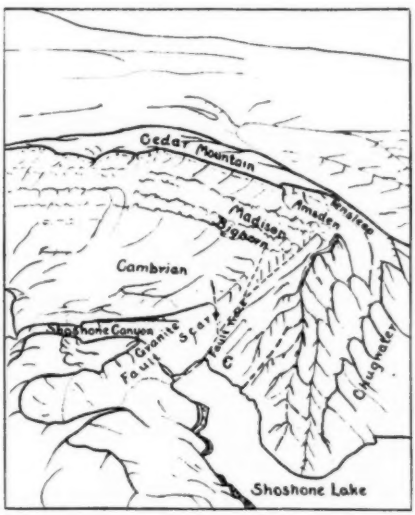


FIG. 4.—View southeastward across Shoshone Canyon and dam, showing relation of steep west limb of Rattlesnake Mountain "anticline" to basement fault and edge of uplifted basement block.

unknown, because of the extensive veneer of Eocene sedimentary rocks which partially or completely overlap and conceal many of the pre-Wasatch deformational features. The margins of the basins are roughly paralleled by numerous minor uplifts, many of which may be true compressional domes and anticlines. Many of these features, however, show the strong asymmetry of cross section observable in the Rattlesnake Mountain "anticline," which is revealed by canyon exposures to be the result of the "trap-door" elevation of a tilted basement block, bounded on its elevated edge by a deep-seated fault which underlies the steep limb of the "fold" (Figs. 3 and 4).

One noteworthy structural feature of the northern part of the Big Horn Basin is the line of faulting and folding (parallel to the Lake Basin *en échelon* fault zone) which extends from the central east-west monocline of the Pryor Mountains through the Dry Creek oil field; the Roscoe, Dean and Nye domes; and the Stillwater and Livingston anticlines.

RESULTS OF STRUCTURAL RESEARCH WORK IN BEARTOOTH-BIGHORN REGION

In addition to the ascertainment of significant details of local structure mentioned in the foregoing pages, other results of the structural studies in the Beartooth-Bighorn region may be summarized as follows.

1. The nature of the individual structural features studied indicate that they are characteristically the products of basement block or wedge elevation, or rotation under regionally applied compression —rather than the products of simple folding under tangential compression. The recurrence of characteristic structural trends throughout the area indicates that a system or systems of pre-Cambrian faults or lines of weakness have defined the afore-mentioned basement blocks or wedges, or both.

2. The merging of monoclines into thrust faults, and the magnitude of the thrusting both seem directly related to the extent to which the basement rocks have been elevated in the uplifted (and overthrust) structural element. Thus, in the Pryors, where relative uplift of the northeastern corner of the southeast block is about a mile, overthrusting is incipient. On the west flank of the Bighorns along the Kane-Sheridan highway, where relative uplift is about two miles, the (westward) overthrusting is of the order of magnitude of half a mile. On the east side of the Bighorns, south of Sheridan, where the uplift is considerably greater, the (eastward) overthrusting is much more extensive, and similarly along the Beartooth front between Clark Fork

TABLE II

GEOLOGICAL AND GRAVITY PROFILE—BOXELDER, SOUTH DAKOTA, TO CODY, WYOMING*

Pendulum Station Location	*Sta. No.*	*Altitude (Feet)*	*Calculated Anomaly*	*Stratig. Position of Station*	*Estimated Thickness of Sedimentary Formation beneath Station (Feet)*			
					Post-Cretaceous	*Mesozoics*	*Paleozoics*	*Total*
Boxelder, S. Dak.	357	3,005	+16	Upper Pierre	0	4,225	650	4,875
Rapid City, S. Dak.	358	3,395	+42	Top of Minnekahta	0	0	1,300	1,300
Pactola, S. Dak.	359	4,495	+53	Top of schist	0	0	0	0
Tigerville, S. Dak.	360	5,840	+57	Top of schist	0	0	0	0
Moon, S. Dak.	363	6,325	+57	Near top of Minnelusa	0	0	750	750
Newcastle, Wyo.	270	4,350±	+29	Newcastle sandstone	0	1,535	1,415	2,950
Osage, Wyo.	364	4,360	+28	Top of Mowry	0	1,775	1,415	3,190
Kara, Wyo.	365	4,320	+25	Top of Pierre	0	5,425	1,415	6,840
Moorcroft, Wyo.	202	4,220±	+21	In Lance	900	5,370	1,465	7,735
Gillette, Wyo.	366	4,550	+23	In Wasatch	3,600	5,445	1,600	10,745
Ulm, Wyo.	367	4,555	−20	In Wasatch	4,700	5,850	1,800	12,350
Acme, Wyo.	369	3,675	+6	In lower Feet Union	2,600	6,250	2,350	11,200
Ranchester, Wyo.	370	3,790	+5	Top of Lance	1,600	6,425	2,400	10,425
Dayton, Wyo.	371	3,975	+5	Top of Mowry	0	3,450	2,500	5,950
Steamboat Pt., Wyo.	372	7,880	+59	Top of Granite	0	0	0	0
Burgess Ranger Station, Wyo.	373	8,015	+65	Top of Granite	0	0	0	0

* Gravity observations and anomaly computations made by U. S. Coast and Geodetic Survey.

Determination of stratigraphic position of stations and estimates of thickness of sedimentary formations by W. T. Thom, Jr.

TABLE II (*Continued*)

Pendulum Station Location	*Sta. No.*	*Altitude (Feet)*	*Calculated Anomaly*	*Stratig. Position of Station*	*Estimated Thickness of Sedimentary Formation beneath Station (Feet)*			
					Post-Cretaceous	*Mesozoics*	*Paleozoics*	*Total*
Medicine Mt., Wyo.	374	9,110	+71	Top of Granite	0	0	0	0
Five Springs Bench, Wyo.	375	4,075	+27	Top of Thermopolis	0	2,150	2,550	4,700
Kane, Wyo.	380	3,625	+10	Top of Frontier	0	2,900	2,750	5,650
Lovell, Wyo.	381	3,920	−14	Top of Niobrara	0	4,400	2,900	7,300
Garland, Wyo.	382	4,290	−27	Top of Lance	500	6,630	3,250	10,380
Eagle, Wyo.	383	4,685	−32	In Wasatch	4,900	7,050	3,050	15,000

Canyon and Nye the area of maximum overthrusting seems closely connected with the locus of maximum elevation of the crystalline core of the uplift. This seems to bear on the thickness of the competent crystalline shell underlying the sedimentary rocks of the region.

3. A study of the relation of gravity anomalies along geologic profiles extending across the Black Hills, Powder River Basin, Bighorns, and Big Horn Basin show a strikingly close relationship between the size and sign of the gravity anomalies at selected pendulum stations and the estimated depth to the base of the Cambrian at these stations (Fig. 5). Such departures as exist are probably due to the existence of near-by uplifts, concealed beneath the unconformable Wasatch deposits.

4. A study of the joint systems developed in the pre-Cambrian crystalline rocks involved in the thrust on the west side of the Bighorns, and a supporting petrographic study of this granite, together indicate that the sharp flexing of the upper surface of the granite induced by drag attending the thrusting, has been accomplished by distributed movement upon joints, and has not resulted from re-crystallization or "flow" in the granite.[1]

5. It has been observed that small porphyry intrusions are commonly found along the traces of the thrust faults surrounding the

[1] C. W. Wilson, Jr., unpublished manuscript.

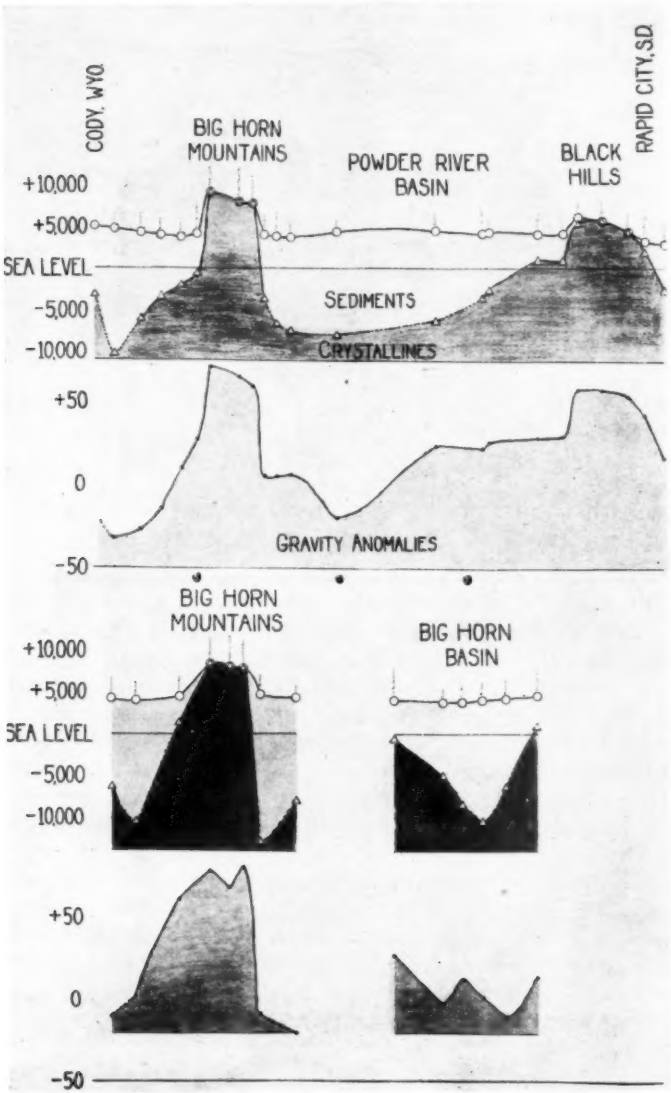


FIG. 5.—Local geology and gravity anomalies.

Beartooth uplift, and that porphyry stocks, dikes, and sheets cut the older crystallines in the central part of the uplift. It is not as yet known that these porphyries are derived from a common magmatic reservoir or that their intrusion was accomplished simultaneously, or coincident with the elevation and overthrusting of the Beartooth Range (underthrusting of the contiguous depressed blocks). The recurrence of such intrusions in critical structural positions throughout the Beartooth area is, however, too frequent for such occurrence to be merely accidental.

6. The region is featured by a succession of high-level erosion surfaces, the development of which may be correlatable with the deposition of fossiliferous basin deposits or terrace gravels of known or ascertainable age. It may thus be possible to date the various deformational episodes closely, and ascertain whether elevation has recurred as down-cutting has progressed, or whether uplift was completed within a brief time, geologically speaking, with down-cutting progressing at a varying rate due to the fluctuation of climatic or other factors. This will be one of the studies upon which attention will be particularly centered during the coming summer.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), PP. 694-712, 10 FIGS.

ANALYSIS AND EFFECTS OF CURRENT MOVEMENT ON AN ACTIVE FAULT IN BUENA VISTA HILLS OIL FIELD, KERN COUNTY, CALIFORNIA[1]

THOMAS W. KOCH[2]
Taft, California

ABSTRACT

Recently it has been found that casing failures in twenty-two wells lying on the south flank of Buena Vista anticline have been caused by movement on an active thrust fault. Surface evidence of the rate and recency of movement on it is given by its newly made scarp and by the buckling of gas, oil, and water lines at and near its trace. The fault strikes N. 75° W. and dips 25° northward, or into the south flank of the structure. Computations made from measurements on bent pipe lines and collapsed casings show that the overriding block is moving southward at a minimum average rate of 1½ inches per year. The fault probably is the result of differential slipping between beds on the north flank of the structure induced by current folding.

INTRODUCTION

Investigation of the cause for the collapse, during a period of several years, of the casings in twenty-three wells in the Buena Vista Hills oil field, Kern County, California, recently brought to light the existence of an active thrust fault in this area. Although the surface trace of the fault has been found to be marked by a well defined recent scarp, its significance was not recognized previously and it is probable that, except for the economic importance of the loss of the wells, this extraordinarily interesting phenomenon might have escaped detection.

Pipe lines, laid approximately at right angles to the surface trace of the fault, were found to be deformed by the recent movements. Measurements on these deformed pipe lines and data obtained from the histories of the wells with collapsed casings have permitted calculation of the rate of movement on the fault. Furthermore, as the faulting appears to be related directly to current folding of the Buena Vista anticline, approximate figures can be computed for the rate of folding of this structure. Current folding probably is not confined to the Buena Vista anticline and, no doubt, is going on in other San Joaquin Valley structures having youthful physiographic development.

[1] Read before the Pacific Section of the Association at Los Angeles, California, November 3, 1932. Manuscript received, March 16, 1933.

[2] Geologist, Standard Oil Company of California.

ACKNOWLEDGMENTS

For his active support in making this paper possible, the writer expresses his appreciation to G. C. Gester; for aid and constructive criticism in working up the problem, he is grateful to G. M. Cunningham; for discussions and data on the McKittrick and north Buena Vista Hills area, he is indebted to J. B. Stevens, of the Associated Oil Company; and for their interest in furthering the problem and their discussions of it, the writer is very grateful to H. O. Wood, of the Carnegie Institution, and J. P. Buwalda, of the California Institute of Technology.

LOCATION

The Buena Vista Hills, through which the thrust fault passes, lie on the west side of the San Joaquin Valley, California, about 35 miles southwest of Bakersfield and 2 miles north of Taft. They form a spur from the Temblor Mountains, which bound the southern San Joaquin Valley on the west. The foothills of the Sierra Nevada Mountains lie about 60 miles east of them.

GENERAL RELATIONS

The Buena Vista Hills represent the youthful physiographic expression of Buena Vista anticline. Trending from N. 45° W. to N. 65° W., they lie between the Elk Hills uplift on the north and the highly folded Temblor Range on the southwest. Major synclines separate them from these uplifts. The active San Andreas rift, 12 miles southwest of them, lies at the southwest foot of the Temblor Range.

In the Temblor Range, back of Taft, are exposed beds as old as Oligocene, but the surface formation of the Buena Vista Hills is of Tulare (Pleistocene) age. The section penetrated by wells along the crestal part of the Buena Vista anticline is generalized in Table I.

TABLE I

	Feet	
TULARE (Pleistocene)	0–1,000	Sands, gravels, conglomerates. Minor amounts of yellow clay
SAN JOAQUIN CLAYS (Pleistocene-Pliocene)	1,000–2,300	Clays and shales with minor beds of sandstone
	2,300–2,350	Oil sands. (Basal San Joaquin clays producing horizon)
ETCHEGOIN (Lower Pliocene)	2,350–2,850	Sands and sandy shales carrying some oil
REEF RIDGE (Upper Miocene)	2,850–3,400	Clay shales, slightly sandy at top
MARICOPA (Middle Miocene)	3,400+	Grayish brown to black, organic siliceous shales

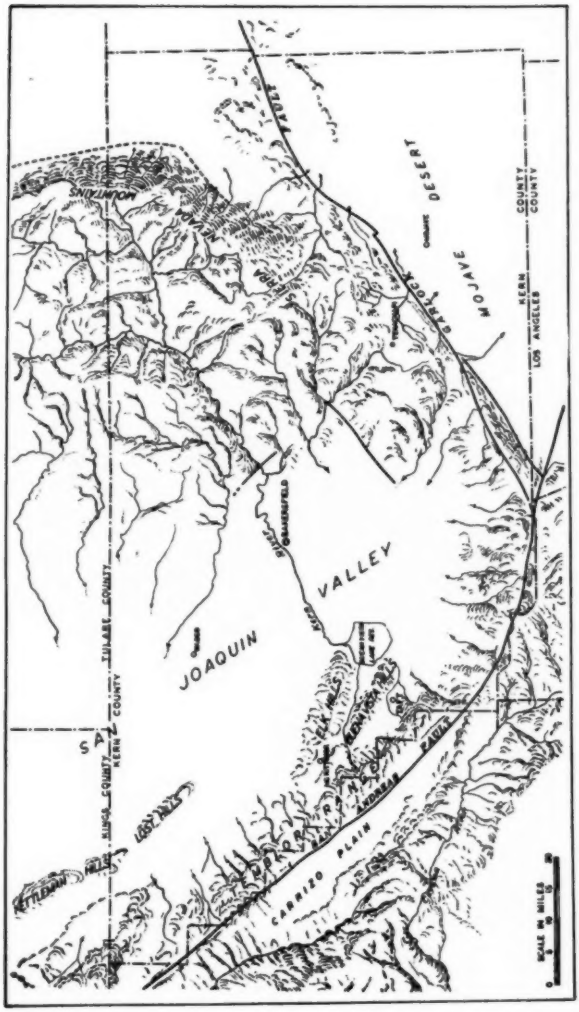


FIG. 1.—Index map of Kern County, California, showing principal faults, from *Fault Map of California, Seis. Soc. Amer.* (1922).

Of primary interest are the sands, gravels, conglomerates, and clays of the Tulare and San Joaquin clays formations, as the fault apparently does not extend far into the Etchegoin.

SURFACE FAULT EVIDENCE

Physiography.—Both surface and subsurface data are in perfect accord as to the position, dip, and rate of movement of the Buena Vista fault. However, character of movement must be determined largely from surface observations.

The surface trace of the fault is a well marked line on the ground which runs through the N. ½, N. ½ of Sec. 7, T. 32 S., R. 24 E., and extends for a short distance into Sec. 12, T. 32 S., R. 23 E., and Sec.

FIG. 2.—Looking east along recent scarp of Buena Vista fault in N. ½ of Sec. 7, T. 32 S., R. 24 E. Note buckled 6-inch water line in upper left corner.

6, T. 32 S., R. 24 E. It may be recognized for a distance of about 1½ miles. Its average trend is N. 75° W. It is essentially a straight line, showing lobes and reëntrants only in minor detail. The dip of the fault plane, as determined from surface measurements alone, is about 15° N. However, subsurface data indicate the true dip to be nearer 25° N.

Above the fault trace, or north of it, are exposed light-colored, soft, quartzose sands, carrying a few thin clay beds. Dips are poor on account of the unconsolidated character of the material, but where measurable, they are from 4° to 7° N. The oil sands immediately beneath dip from 5° to 10° S.

South of, or below, the fault trace, is a smoothly sloping plain of reddish to yellowish brown, clayey sand, which offers a sharp contrast to the lighter-colored material on the north. It is essentially a south dip slope on which has been spread a thin veneer of recent wash.

FIG. 3.—A 4-inch abandoned oil line along east line of Sec. 7, T. 32 S., R. 24 E., looking east. It has been shortened 1.50 feet in 13 years.

FIG. 4.—Abandoned 2-inch fuel line in N. ½ of Sec. 7, T. 32 S., R. 24 E., showing character of buckling it suffered at trace of Buena Vista fault.

FIG. 5.—Same 2-inch fuel line shown in Figure 4, but looking eastward along trace of fault. The 6-inch gas line in right middle distance has been repaired recently and lies flat across fault.

FIG. 6.—Four-inch gravity oil line near center of N. ½, N. ½ of Sec. 7, T. 32 S., R. 24 E, shortened 1.40 feet in 11½ years.

Immediately at the fault trace may be seen the initial fault scarp standing at a maximum of 4 feet above the smooth plain. It is so youthful looking that it might have been formed in the past year. Then, breaking away at a less slope, but still considerably steeper than the frontal plain, is the eroded scarp, rising at about 100 feet

FIG. 7.—Joint of 6⅝-inch casing from Honolulu Oil Company No. 22, Sec. 8, T. 32 S., R. 24 E., bent at least 6 inches by shearing action of Buena Vista fault.

above the plain. It breaks away at the top into a comparatively flat upland surface. Dissection has been rapid in the soft sediments of the overlying block. In it the streams have cut sharp gulches which disappear abruptly at the fault trace. The material eroded from the overlying block has been dropped by the streams almost immediately at the fault trace.

By assuming that the upland surface and the smooth frontal plain, 100 feet below, at one time were continuous, a figure of about 200 feet is derived for the probable total slip on the fault. On account of the looseness and lenticularity of the Tulare formation, this can not be checked by structure mapping. On the further assumption that the movement has gone on at a constant rate since it began, the fault commenced its movement from 800 to 2,400 years ago.

Bent pipe lines.—Further and more striking evidence of the reverse character, the recency, and the rapidity of movement of the Buena Vista fault is given by the histories of pipe lines, which have been laid more or less normally across the fault. Eight of these have buckled out of the ground and now rise from 2 to 4 feet above the surface, resembling croquet wickets across the fault trace. Measurements indicate that these pipes have been shortened approximately 9–19 inches in 9–15 years.

Earthquakes.—In spite of the rapid movement, no earthquakes are recorded which might have originated on the fault.

FAULT EVIDENCE FROM DRILLED WELLS

Subsurface evidence of faulting is given by a group of twenty wells situated in Sec. 1, T. 32 S., R. 23 E. and Sec. 6, 7, and 8, T. 32 S., R. 24 E., whose casings either have collapsed or bent to such an extent as to cause trouble in cleaning out the wells. Indeed, several wells have been abandoned because tubing would no longer pass through the oil string. The first suggestion of trouble commonly comes when full-sized tools no longer will pass through the inmost casing. Later, smaller tools, then even small tubing, perhaps, refuse to pass through. On pulling out the pipe above the fault, the bottom joint which lay in the fault zone ordinarily is found to have been bent into a sigmoid curve through a distance ranging from 5 to 15 feet. The offset may be as much as the diameter of the pipe. Thus, in a 17-inch hole, carrying two strings of ordinary weight casing, an offset of 6 inches in the $6\frac{5}{8}$-inch oil string represents an actual earth movement of $15\frac{1}{2}$ inches.

The casing failures referable to the Buena Vista thrust occur at depths ranging from 76 to 794 feet below the surface. Deeper disturbances of casing probably are occurring, but to date they have not been of such a nature as to cause any recognizable damage to the wells. By referring these depths to a sea-level datum and contouring the surface, a plane is developed whose strike is N. 75°–90° W., whose dip is 24°–26° N., and whose intersection with the surface coincides exactly with the trace of the Buena Vista thrust. The computed mini-

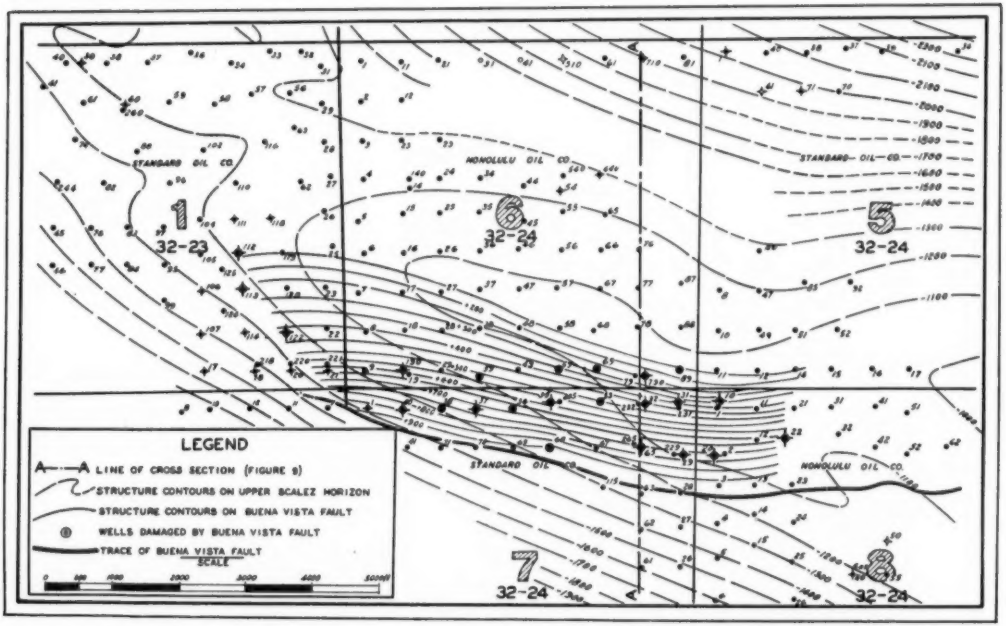


FIG. 8.—Part of Buena Vista anticline, showing structure contours on Upper Scalez marker horizon and on Buena Vista thrust fault.

mum earth movements required to produce these casing failures range from 5.8 to 15.75 inches in a period ranging from 4.1 to 17 years.

MEASUREMENT OF RATE OF FAULT MOVEMENT

Pipe-line data.—The actual amount of movement per year on the Buena Vista fault may be given minimum values from computations on bent surface pipe lines and on collapsed well casings. On the surface, bent pipe lines may be measured around the bend and along the original ditch between comparatively undisturbed points on either side of the bend. Knowing the date of laying the line, its slope and bearing, and the dip of the fault plane, the formula

$$S = \frac{m}{\cos(\alpha+\beta)\cdot\cos\gamma\cdot T}$$

gives a very close approximation for the dip slip per year on a low-angle thrust, where S is the dip slip per year, m the measured shortening of the pipe line, T the time the line has been in the ground, α the dip of the slope on which the line was laid, β the dip of the fault, and γ the angle between the pipe line and the direction of movement on the fault.

The application of this formula to four lines in Sec. 7, T. 32 S., R. 24 E., on which reliable data are available, results in the rates shown in Table II.

TABLE II

	Feet per Year
6-inch gravity oil line at east side of section	.266
4-inch abandoned oil line at east side of section	.139
2-inch abandoned gas line near center of north half of section	.17
4-inch gravity oil line near center of north half of section	.145

The lines have been in the ground 9–13 years and have been shortened from 1.40 to 1.80 feet. Obviously, these are minimum figures by reason of the fact that there must be some underground slippage before a pipe line will be held firmly enough in its ditch to be buckled out at the fault by earth movements.

Well data.—Figures of similar magnitude may be derived by a consideration of collapsed and bent casing. Knowing the original diameter of the hole, the thickness of casings, the largest tools or pipe that will pass through the damaged casing after a certain number of years, and the dip of the fault plane, the dip slip per year may be computed by the formula:

$$S = \frac{D - (t_1 + t_2 + t_3 + etc.) - d}{12 \cdot T \cdot \cos \beta}$$

where D is the diameter of the original hole, t_1, t_2, t_3, et cetera, the difference between inside and outside diameters in inches of casing in the hole, d the diameter in inches of the largest tool that will pass through the damaged casing after T years, and β the dip of the fault plane.

This formula is based on the assumption that the dip slip is the net slip—an assumption which is essentially true for the Buena Vista fault.

Table III shows casing failures and computed rates of fault movement. The average net slip figure for twenty-two wells is .131 foot per year, the extremes .076 to .224 foot per year. Like those for bent pipe lines, these are probably minimum figures on account of (1) crushing and redistribution of sand particles before actually bending or collapsing the casing; (2) increased size of hole over listed size of bit used; and (3) in bent casing, long bends, allowing tools or pipe to pass through without appreciable interference. One contrary factor is the possibility of the presence of several collars within the collapsed or bent pipe, all situated at or close to the fault. These would tend to decrease the amount of movement required to pinch off or bend the inmost string of pipe.

EVIDENCE OF MOBILITY IN AREAS NEAR BUENA VISTA FAULT

Other casing failures.—Casing failures of a nature similar to those resulting from the Buena Vista thrust are common in Sec. 1, T. 32 S., R. 23 E. To date, there have been sixteen such failures, of which ten, grouped in the southeast quarter of the section, may be correlated and contoured. The resulting surface lies at depths ranging from 630 to 800 feet below sea-level and is approximately parallel with the bedding in that area. The speed of movement on this plane varies from .12 to .17 foot per year. Apparently, in Sec. 1, T. 32 S., R. 23 E., in addition to the effect of the Buena Vista fault, which is recognized in several wells, there is taking place an adjustment between beds at a rate slightly less than that on the fault. Other sporadically distributed casing failures reported in Sec. 1, T. 32 S., R. 23 E., and occasionally from the north flank of the structure, suggest current bedding movement throughout the vertical section on both flanks of the fold.

Evidence of other recent folding.—A very interesting situation, recently brought to the writer's attention,[1] is the presence of a badly

[1] Pointed out by J. B. Stevens, Associated Oil Company, Fellows, California

TABLE III

Well No.	Depth to Bad Pipe Feet	Elevation in Feet Well	Elevation in Feet Fault	Casing (Inches)	Size of Hole Inches	Total Movement Inches	Years	Dip Slip Ft. per Yr.	Formation Logged by Driller
				Sec. 7, T. 32 S., R. 24 E.					
29	292	1,069	777	10¾; 8⅝; 5	15	15.75	15	.1035	Shell, boulders
31	626	990	364	11¾; 8⅝	17?	13.5±	6.8	.1815±	Clay, boulders
32	526	1,003	477	11¾; 8⅝; 6¼	17	11.75	7	.1545	Sand, boulders
33	502	1,040	539	12½; 10; 6¼	17½	12.35	9.3	.122	Yellow clay, sand streaks
35	389	1,006	627	15½; 10; 6¼	15½?	12.0±	7.6	.145±	Surface sand
36	331	1,034	703	11¾; 8¼	17?	15. ±	9.5	.145	Coarse sand
						7.5±	3.3	.189	
37	280	1,042.5	762.5	11¾; 6¼	17	13	7.2	.1645	Hard sand, clay, boulders
38	199	986	787	11¾; 8¾	17	10	4.1	.224	Surface sand, boulders
40	125	973	848	10; 6¼	17	13.5	8	.155	Surface sand
65	300	1,054	754	12½; 10; 8⅝; 6¼	17?	12.5±	8.75	.131	Sand, streaks, clay
68	76	996	920	10¾; 6¼	15½	11.5	6.16	.172	Sand
				Sec. 6, T. 32 S., R. 24 W.					
190	600	1,015	415	10; 6¼	16				Sand, boulders
39	475	991	516	10; 6¼	16	8.5±	7.15	.104	Sand, clay, boulders
59	595	966	371	12½; 10; 6¼	17?	11±	8.5	.119	Hard sand, clay
69	697	964	267	12½; 10; 6¼	18	11.75	9.8	.0908	Shale
790	715	1,002	287	10; 8⅝; 6¼	16?	13.75±	12	.105±	Hard sand, shell
89	794	958	164	12½; 10; 6¼	18	13.0	7.16	.1665	Hard sand, clay
				Sec. 8, T. 32 S., R. 24 E.					
10	682	1,037	355	12½; 8⅝; 6¼; 4¾	18?	15.75	17	.085	Boulders
20	301	1,081	750	10¾; 8⅝; 4¾	16?	11.5	13.5	.078	Gravel, boulders
22	341	998	657	10; 10¾; 8⅝; 6¼	15½?	13.25	16	.076	Sandy clay, boulders
				Sec. 1, T. 32 S., R. 23 E.					
112	687	801	114	11¾; 8¼	17	5.8	5.66	.094	Clay, gravel
113	542	813	271	11¾; 8¼	17	6.8	5.8	.107	Hard sand
122	474	903	429	11¾; 8¼	17?	11.5	8.8	.119	Sand, boulders
					17	8.5		.088	

warped pipe line between the Associated Oil Company's Nos. 73 and 83, in Sec. 26, T. 31 S., R. 23 E., about 3 miles northwest of the Buena Vista fault. It was laid across a minor syncline on the general Buena Vista uplift and its warping is undoubtedly due to recent compression of the syncline. The action of the Associated No. 73 is also indicative of current folding in the area. In completing the well, a strain was taken on the casing, stretching it about a foot. While working on the well recently, it was found that the casing was no longer under tension, but had actually been forced out of the hole and now stands a foot or more above the blocks on which it originally was hung. Several other cases of unduly warped surface pipe lines and peculiar casing action in the Buena Vista Hills also are suggestive of earth movements, but to date they have not been correlated with any definite structural feature.

Evidence of concurrent deposition and folding.—Further, account must be taken here of the evidence given by the known thinning and even complete absence of some beds across the anticlinal axes, not only of the Buena Vista anticline, but also of the adjacent structures of the west side of the San Joaquin Valley. Beds of Pliocene and Pleistocene age, and probably also of Miocene age, show decidedly greater thickness in the synclines than on the anticlines. Such thinning is distributed throughout the Pleistocene-Pliocene section, and is not confined definitely to one horizon of great unconformity. Flanking dips on the oil sands at depths of about 3,500 feet, are, in some places, 10°–15° higher than in the surface beds. Manifestly, folding in the area has progressed concurrently with deposition since the beginning of Pliocene time, or before.

ORIGIN AND SIGNIFICANCE OF BUENA VISTA THRUST FAULT

Origin of fault.—The Buena Vista thrust fault apparently originates in a bedding slip on the north flank of the structure. Moreover, it appears to be the result of differential movement during growth of the anticline. By projecting the fault down the dip for 2 miles, it passes into beds having a slope slightly less than that of the fault itself. A flattening of 10° in the fault's dip would make it coincident with the bedding. In addition, it may be seen on the accompanying contour map (Fig. 8) that it carries the same undulations as the beds into which it appears to pass. Taken in conjunction with the fact that in Sec. 1, T. 32 S., R. 23 E., there is what appears to be bedding fault movement, shearing casing at a rate only slightly less rapid than on the Buena Vista fault, it is fairly certain that the Buena Vista fault had its origin in a bedding slip.

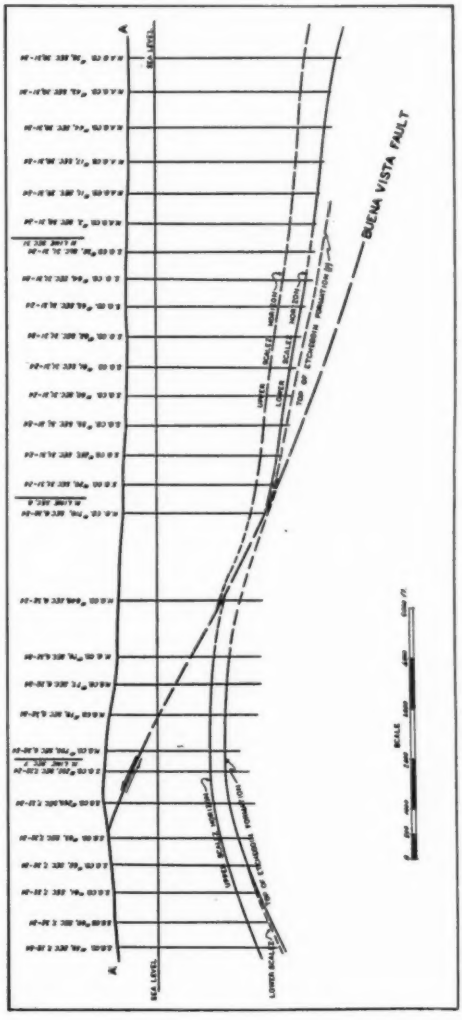


FIG. 9.—North-south section through Buena Vista anticline near east line of Sec. 7, T. 32 S., R. 24 E. Buena Vista thrust is an active fault moving at present at from .076 to .224 foot per year.

The direction of thrusting on the fault is such as to shift the overlying block southward. This movement, if extended back into the bedding plane of the north flank of the structure, is seen to correspond with the required movement toward the anticlinal axis of upper beds over lower, during the growth of a fold.

That the Buena Vista anticline started its growth not later than the beginning of Pliocene time is shown by the anticlinal thinning, or structural convergence in the post-Miocene formations; that it is growing at a measurable rate is shown by the activity of the Buena Vista thrust fault and of the bedding faults in Sec. 1, T. 32 S., R. 23 E.

Rate of growth of fold.—The rate of elevation of an anticlinal fold and the shortening of the earth's crust occasioned thereby vary considerably from the ideal situation in any given fold because of such unknown factors as competency of sediments, compressibility of sediments, depth and character of folding, region of application of stresses, et cetera. A simple fold, composed of competent, elastic material, which retains a simple sine curve in cross section and which has maximum flanking dips of 25°, is elevated above the median line at an approximate rate of 1.25 times the horizontal shortening, or roughly 2.25 times the absolute movement on one flank parallel with the bedding plane. If the fold is unable to bury its complementary syncline beneath an absolute datum, the anticline must grow in absolute elevation at twice this rate. The ratio of shortening to elevation, that is, 1.00 to 1.25, was found by purely empirical means,—by folding a celluloid spline and drawing a curve from the measurements taken during progressive folding. 1.25:1.00 is the slope of the curve at 25°. The figure 2.25 is simply $2 \times 1.25 \times \cos 25°$. Average maximum flanking dips on the Buena Vista anticline at the depth where the fault coincides with the bedding are about 25°. The movement on the fault is a measure of the absolute shortening, parallel with the bedding, of one flank of the fold. Hence, the fold probably is rising at an approximate rate of 2–4 times the movement on the fault, or from about 0.2 foot to 0.5 foot per year.

Character of fault in depth.—The rate of slip on the fault appears to decrease with depth.[1] Wells whose casings have been damaged by the fault all lie within $\frac{3}{8}$ mile of the fault trace. The deepest failure to date occurred at a depth of 794 feet. The point of maximum differ-

[1] According to Theodore A. Link, "Individualism of Orogenesis, Suggested by Experimental Data," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, No. 4 (April, 1931), pp. 399–403, this evidence may be indicative of underthrusting with the active force operating from the south northward in this case. He says (p. 400): "In almost all experiments, *underthrust faults develop at the surface near the push-block, and show less and less*

ential movement between beds in an ideally growing fold lies at a point midway between the anticlinal and the synclinal axes. From this point, the amount of movement normally decreases in both directions, becoming zero at the anticlinal and the synclinal axes. This would be the case also in the upper beds of the Buena Vista anticline, were it not for the presence of the Buena Vista fault. In the syncline, north of the Buena Vista anticline, presumably it is the case, but toward the anticlinal axis, the fault has freed the overriding block from this effect and it may now move at the maximum rate throughout the free portion. However, well failures have occurred only in a narrow shallow zone near the trace, indicating either greatest movement, or most concentrated movement, that is, narrowest fault zone, near the outcrop of the fault. It seems impossible that the shift in the center of the north flank of the anticline could be less than the shift at or near the fault trace. Admittedly, in the frontal portion of the overriding block, the gravitational load is less and therefore the relief is easier. The necessary inference is that the shift remains constant from the middle of the north flank of the anticline to the surface trace of the fault, but that the slip increases in amount toward the surface trace. Thus, north of the area of recognizable bent casings, the casings presumably are still offset the same amount, but that offset is distributed through a thicker zone. The sigmoid curve is gentler and casing troubles do not develop as fast as they do near the fault trace. This sort of action may be demonstrated experimentally. The supposed action is indicated in Figure 10.

In this connection, it is to be noted also that in the Buena Vista Hills the first 1,000 feet of section penetrated by the wells is largely coarse material. Appreciable beds of clay and clay shale begin to appear at about 800 feet, but they do not become abundant above 1,200–1,500 feet. Below 1,500 feet, the section carries more clays than sands and conglomerates. Very likely the greater competency under compression of the sandy and gravelly beds, however unconsolidated, over the soft plastic clay shales, however loaded, has been a contributing factor to the localization of movement immediately at the fault plane in the upper 1,000 feet of beds.

Ultimate origin of forces.—The Buena Vista thrust appears to be so closely related to and dependent on the folding of the Buena Vista anticline that the ultimate origin of the forces developing the fault

displacement away from the push-block, or the source of stresses." However, continuing, he distinguishes between thrust faults which are related to, or caused directly by, the primary stresses—his rule refers to these—and thrust faults of local origin, the result of secondary stresses, commenced while adjustment is made to the primary cause. Apparently, the movement on the Buena Vista fault belongs to the latter class.

must be the same as that which developed the fold. These are regional forces which were no doubt responsible for most, if not all, of the folding of the west side of the San Joaquin Valley. The commonly held view is that the west side structures have developed in part from the uptilting on the east of the great Sierran block, pinching the sediments in the angle against a massif, presumably immediately west of the San Andreas fault; in part by an uptilting of the Temblor Range from the southwest; in part by a rotational or shearing action related to the horizontal component of the movement on the San Andreas fault. It is not known what the absolute direction of movement of

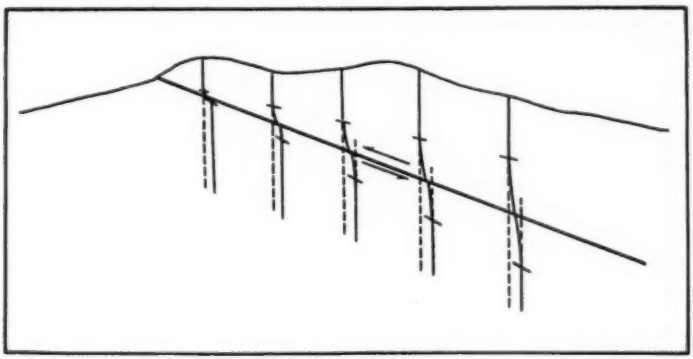


FIG. 10.—Diagrammatic sketch of thrust fault with constant shift but increased slip toward surface.

faults and folds may be. The relative movement on the San Andreas fault is such that the block on the west apparently is moving northward without much, if any, vertical displacement. However, from what has gone before, it is seen that as far as the Buena Vista thrust is concerned, the Buena Vista structure may be considered a closed system in which the essentially horizontal forces developing the fault probably acted from the north and south normal to the strike of the fault.

RECENT EARTH MOVEMENTS IN ADJACENT REGIONS

For many years, it has been known that the San Andreas fault, extending from Bolinas Bay on the north (where it passes into the Pacific Ocean) to the San Bernardino Desert on the south, is an active fault on which movements occur periodically, usually with the production of earthquakes. According to Reid,[1] the movement takes

[1] H. F. Reid, "The Elastic Rebound Theory of Earthquakes," *Bull. Dept. Geol. Univ. of California*, Vol. 6, No. 19 (1911).

place by elastic rebound. Strains accumulate in the rocks for a time and then are relieved suddenly by snap faulting. In 1906, a horizontal movement of 20 feet was recorded at the time of the San Francisco earthquake. The San Andreas fault passes 12 miles southwest of the Buena Vista Hills.

On the east side of the San Joaquin Valley, about 40 miles northeast of the Buena Vista Hills, there are several active faults in the Sierran granitic mass. An earthquake, occurring in July, 1932, had its epicenter on one of these, namely, the Kern River fault, a high-angle normal fault.

Less than 10 miles northwest of the Buena Vista Hills, and on the same general line of uplift, is the faulted area of the McKittrick oil field. Both low- and high-angle thrust faults occur in this region of structural complexity.[1] One or more of them are active at present, for the concrete highway, a mile south of the town of McKittrick, is being buckled up to such an extent as to necessitate repairs about once every two years. Stevens[2] has set triangulation hubs across the area of disturbance from which he computes the movement to be at the rate of about .8 inch per year.

These data show that the Buena Vista fault is not alone in indicating crustal instability in California. Probably faulting and folding at a rate comparable to that of the McKittrick area and the Buena Vista Hills is going on at present on other San Joaquin Valley structures. Here again is geological activity in the present giving us a key to the type of action of the past.

ECONOMIC ASPECTS OF BUENA VISTA FAULT

The cost of well repair work and the loss of wells and oil, resulting from the active movement on the Buena Vista fault, is estimated at about $500,000.00. The average life of casing in a well through the fault is 8 years. The well, itself, should be made to produce for approximately 20 years, but in many places it is not profitable to redrill a location after 8 years with the expectancy of only a stripper well. Various types of repair work have been attempted.

The early thought was that the collapsed casings resulted simply from sloughing or caving formations and it was attempted to roll them out. The practice was found to be unsuccessful and it was abandoned.

[1] W. A. English, "Notes on the McKittrick Oil Field," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, No. 6 (June, 1927), pp. 617–20.

[2] J. B. Stevens, Associated Oil Company, Fellows, California, personal communication.

Temporary relief for a year or more may be had in wells whose tubing is pinched by backing or shooting off the inside strings of pipe at the fault and re-running the tubing into the stub of oil string left in the hole. This comparatively inexpensive process is being used at present to some extent.

A more permanent job may be done by washing over the outside string of casing down to the fault with a wash-over shoe of largest possible diameter, pulling all casing to and including the bent joint in the fault, and screwing on new surface strings. In this way, additional space is provided for earth movements around the casing in the overriding block. This method, although giving the best results of any tried, has been excessively expensive due to the slow progress made with a large wash-over shoe and the cost of the special equipment.

For new wells to be drilled through an active thrust block, the proper procedure would be to set large casing at but never through the fault. The reduced size of hole drilled below the fault plane will accommodate small pipe which will move at a known rate through the upper string. Thus, the life of the casing can be computed, or, with various sizes of casing, adjusted to the expected life of the well.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), PP. 713-731, 7 FIGS.

RÔLE OF CAP ROCK IN OIL ACCUMULATION[1]

ROBINSON P. LOCKWOOD[2]
Boulder, Colorado

ABSTRACT

In the first series of experiments described, efforts were made in the laboratory to obtain an accumulation of oil in a sand saturated with salt water under an impervious cap rock. Various agents that have been recognized as of probable assistance in the migration of oil were enlisted to secure the anticipated accumulation of oil in two types of simulated geologic structures. These efforts to secure an accumulation beneath an impervious cap rock resulted in failure.

A porous cap rock was used in the second group of experiments to secure the accumulation of oil. These experiments were successful.

It was found that the cap rock was eventually sealed or made impervious by a process of differential viscosity. This process may have resulted from a chemical reaction between the oil and the sulphate radical, a common constituent of both connate and meteoric water, which increased the viscosity of the oil. The increased viscosity of the oil eventually sealed the cap rock.

ACKNOWLEDGMENT

The writer is indebted to R. D. George of the geological department of the University of Colorado for his criticism of the contents of this paper, to K. A. Gagos of the department of chemistry at the University for his skillful construction of the glass apparatus, and to K. C. Heald and R. W. Clark, both of the Gulf Corporation, for their constructive guidance in the final stages of the manuscript.

INTRODUCTION

The following experiments were conducted for the purpose of actually witnessing the accumulation of oil in a porous water-saturated sand beneath different types of cap rock. Since visibility is the factor of prime importance, the apparatus was constructed of glass. The employment of this material for apparatus precluded the use of pressure as a factor in the accumulation of oil in the laboratory. It is, however, possible that pressure is of relative value only, and that its elimination in no wise alters the fundamental processes of the accumulation of oil.

The method of migration used by the oil in reaching the trap is left to the choice or the imagination of the reader. In these experiments, the oil was forced to make a vertical entrance into the reservoir

[1] Manuscript received, October 13, 1932.

[2] University Fellow at the University of Colorado, 1090 Eleventh Street, Apt. 10.

sand. No problems of sedimentation were permitted to enter into the experiments, lest their peculiarities obscure the relationship of cap rock to reservoir rock.

The materials used in the following experiments were gravel, sand, clay, glass (as apparatus) salt water approximating the salinity of sea water, oil of mixed base with paraffine predominating and testing 36.5° Bé. and pure rubber tubing. On the assumption that the sedimentary rocks of the earth are water-saturated, the gravel, sand, and clay were always saturated with salt water before an experiment was begun.

IMPERVIOUS CAP ROCK

ANTICLINAL ACCUMULATION

This study of the relationship of cap rock to oil accumulation was engendered by the conditions that were found necessary to secure an accumulation of oil on the crest of an anticline. In the following experiments an anticline of glass was used.

FIG. 1.—Accumulation of oil shown in illustration was obtained through partial dehydration of anticlinal crest.

The apparatus is so constructed that fluids can be admitted through the bottom of either limb, or directly beneath the crest, or from the under side of one limb. The purpose of these openings was to determine whether oil would accumulate on the crest when oil and water were admitted through any one of these openings. It was found much more expeditious to fill the anticline with dry sand, and then to

saturate it with salt water, rather than attempt to charge the anticline with wet sand. The opening on the crest acted as an escape for air driven from the sand. There is no need to describe the ease with which the oil accumulated on the crest of the structure when forced through any one of the openings into the water-saturated sand simultaneously with water. It is important, however, to note the conditions which were found necessary for the successful formation of an oil pool. First, it was found that if the sand were completely saturated with salt water, it was impossible to obtain an accumulation of oil. The oil showed no tendency to accumulate on the crest of the structure, but rather to follow the flow of the water through the overflow tube, or to remain in disconnected drops scattered throughout the sand. Second, it was found necessary for the crest of the anticline to be only partly saturated with salt water if oil were to accumulate beneath an impervious cover rock represented by the glass tubing. It is, theoretically, possible for the crest of a reservoir to become dehydrated in several ways, such as the elevation of the land mass, evaporation along an outcropping reservoir sand, or escape of water along fault planes, or through the formation of hydrous minerals. These explanations were insufficient to satisfy a skeptical mind.

TERRACE STRUCTURE

More futile attempts to bring about the accumulation of oil in a water-saturated, anticlinal reservoir beneath an impervious cap rock led to the belief that some important factor of accumulation had been overlooked, and that this factor might be brought to light while working with a different type of structure. For this reason, a terrace was constructed of 2-inch pyrex glass tubing. The dips are 15 degrees.

Salt water and oil were foreed simultaneously into the lower end of the structure so that the oil might migrate up-dip and accumulate on the terrace. Surprisingly, the oil failed to accumulate on the flat part of the structure. It formed a narrow band along the backbone of the structure from the lower end to the upper end. The quantity of oil on the dips was just as great as that on the terrace. This same result was obtained several times. Increasing and decreasing the oil and water pressure failed to change the result. Possibly a falling ground-water level might succeed where a rising ground level had failed. To test the possibility of obtaining an accumulation of oil through the aid of a falling ground-water level, the oil was forced to migrate from end to end as usual, then the water was permitted to escape slowly from the lower end of the apparatus until the descending water level had reached the terrace. The oil followed the descending water sur-

face, but instead of effecting a greater accumulation on the terrace, the oil had been dissipated through the entire thickness of the sand in the higher part of the structure, and showed no inclination to de-

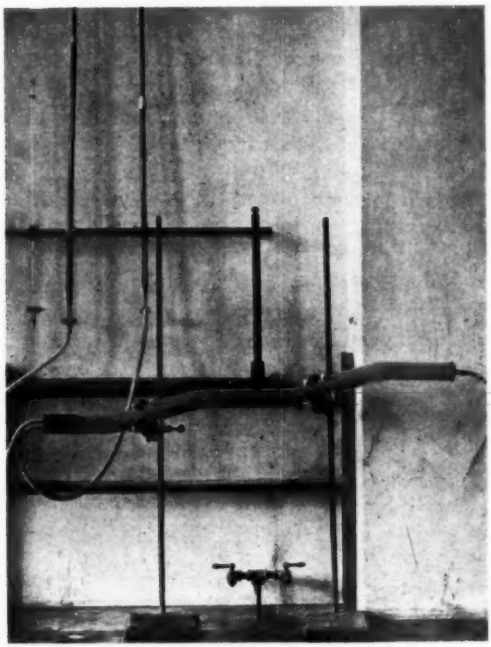


FIG. 2.—Terrace apparatus as it looked at beginning of an experiment.

scend to the level of the terrace. W. H. Emmons[1] secured accumulations of oil with this type of apparatus. His explanation of the procedure is as follows:

A series of experiments was made in the geological laboratory of the University of Minnesota, in which gas was introduced into an oil-soaked sand in a closed system. Tubes about six feet long were bent to form anticlines of which the limbs had slopes of about fifteen degrees. These were filled with sand which had been mixed with oil, sea water, and light gasoline. The tube was completely filled with the mixture and allowed to remain a considerable period. No segregation took place except locally, where the oil gathered into

[1] W. H. Emmons, *Geology of Petroleum* (McGraw-Hill, 1931), pp. 76–79.

small drops. Subsequently, the system was warmed so that the gasoline was vaporized. After forty-eight hours, a considerable segregation of oil, gas, and water had taken place. The gas occupied the highest part of the tube and rested on salt water. The space occupied by the gas represents air spaces which it was not possible to eliminate in charging the water and oil-soaked sand in the tube, together with the space made available by the gas pressure forcing liquids into small cracks of the sand.

This description makes obvious the fact that the two sets of experiments were based on different assumptions of subsurface conditions. It is reasonable to assume from Emmons' description that the gas, oil, and salt water are already in the reservoir rock and the system is closed. That is to say, the occupants of the reservoir sand will not suffer from outside disturbance while their segregation is effected by gravity. If the reservoir sand were just above and in contact with the source rock, and if the crest of the anticline were dehydrated in some manner, then such an accumulation of oil beneath an impervious cap rock as Emmons described might occur. The subsurface conditions postulated for the experiments in this paper are: (1) a completely water-saturated substratum; (2) subsurface conditions which make for a dynamic rather than a static condition (it is reasonable to assume that diastrophism, compaction, changes in geoisotherms, cementation, et cetera, should produce a gradual movement in the subsurface water, and thereby produce a dynamic condition); (3) that the oil migrates a distance, either long or short, before reaching the reservoir sand. By this it is meant that the source rock is not normally in immediate subjacence to the reservoir rock.

The failure to obtain an accumulation of oil in either the anticlinal or terrace structures beneath an impervious cap rock was most unexpected. The difficulty seemed to lie either with the cap rock, or with the water-saturated condition of the reservoir sand. There is, however, a possible explanation for this failure. Perhaps the type of apparatus used by R. Van A. Mills[1] would bring about the desired accumulation of oil beneath an impervious cap rock. A glass aquarium 12 inches long, 10 inches deep, and 8 inches wide was used in this experiment. First, the aquarium was partly filled with salt water (sp. gr., 1.15). Then the glass tubes were arranged in the position as illustrated, with the outlet for the salt water directly beneath the oil and gas outlet. Next, sand varying from 20 mesh to 100 mesh was slowly poured into the aquarium. The sand was stirred at the same time in order that the entrapped air might be liberated. When the water and

[1] R. Van A. Mills, "Experimental Studies of Subsurface Relationships in Oil and Gas Fields, *Econ. Geol.*, Vol. 15 (1920), pp. 398–422.

sand levels occupied the positions illustrated, a watch glass, 6 inches in diameter, was washed beneath the level of the salt water and pressed into the sand, concave side downward, directly above the oil-gas and salt-water outlets. This completed the arrangement of the apparatus, and everything was in readiness for the introduction of the oil, gas, and salt water; 30 cubic centimeters of oil and a small quantity of methane gas were first injected into the sand. After an interval of 10 minutes, no bubbles of oil or gas had reached the sur-

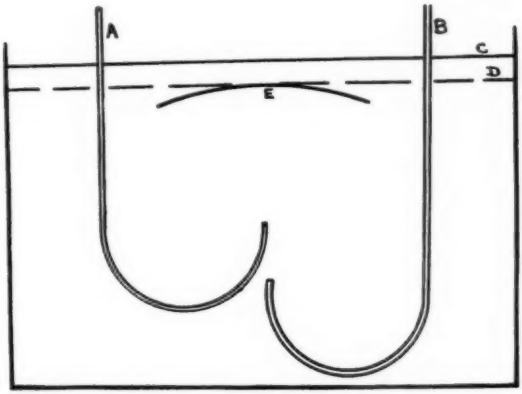


FIG. 3.—Containing vessel is the aquarium. *A*. Oil and gas tube. *B*. Salt-water tube. *C*. Salt-water level. *D*. Sand level. *E*. Watch glass.

face. Salt water was now forced into the sand under a 4-inch head and permitted to flow at the rate of 250 cubic centimeters per hour. Six minutes later, bubbles of gas broke the surface around the edge or beyond the edge of the watch glass, but only occasionally did one appear beneath the watch glass. The oil soon followed the gas and emerged, just as the gas had, near the edge of the watch glass. A few more bubbles of oil than gas appeared beneath the watch glass, but the approximate number of each was almost the same. Ninety-five per cent of the oil and gas had avoided the impervious cover. The oil and gas had possibly traversed lines that in cross section would appear as a cone with the watch glass forming the base. The distance of the apex of the cone beneath the base would depend on a number of variables, such as porosity of the sand, viscosity of the oil, rate of flow of water, curvature of the watch glass, et cetera. Later experiments, in which the gas was injected some time before the injection of the oil,

failed to develop an accumulation of oil beneath the watch glass. It was found possible to force the oil beneath the watch glass by increasing the water head to 30 inches and the flow to 1,500 cubic centimeters per hour. As W. L. Russell[1] has pointed out, it appears improbable that high hydraulic gradients are normal in nature. The hydraulic gradient used in this latter experiment is possibly too high to justify serious consideration of the result obtained. The adoption of the type of apparatus used by Mills failed to change the results obtained with glass tubes in this type of study.

There are two other physical factors which may plausibly assist the migration of oil, and which might effect an accumulation of oil beneath an impervious cap rock. The first is capillary action. W. L. Russell[2] disposes of capillarity in the following statement:

> It seems likely that the capillary force with which water tends to drive the oil out of shales is less than the force required to drive oil through a water wet shale.

The writer agrees with Russell that capillarity is possibly of small value in the migration of oil. He does not, however, concur as to the reason for the lack of assistance. Experiments which depend upon capillary action for the migration of oil are performed through the classical association[3] of a water-saturated sand and an oil-saturated clay or shale. The results are invariably the same. The water migrates into the clay or shale and, through capillarity, forces the oil to evacuate. If this laboratory experiment is thought to simulate subsurface conditions, one basic factor has been overlooked. This factor is that sedimentary rocks, through their origin, are, beyond reasonable doubt, saturated with water throughout nearly all, if not all, of their existence as such. There is no plausible reason to believe that capillary action is operative in a substratum where all of the sediments are water-saturated. Mills[4] and Dodd[5] also agree that the migration of oil through capillary action is highly improbable.

The second physical factor that may aid in the migration of oil, and bring about an accumulation beneath an impervious cap rock, is the buoyancy of oil in the presence of water. Many experimenters

[1] W. L. Russell, "Experiments in Capillarity," *Econ. Geol.*, Vol. 19 (1924), p. 56.

[2] *Ibid.*, p. 57.

[3] C. W. Cook, "Capillarity of Oil and Water," *Econ. Geol.*, Vol. 18 (1923), pp. 167–70.
A. W. McCoy, "A Brief Outline of some Oil Accumulation Problems," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10 (1926), pp. 1015–35.

[4] R. Van A. Mills, *Econ. Geol.*, Vol. 15 (1920), p. 398; Vol. 16 (1921), p. 124.

[5] H. V. Dodd, *Econ. Geol.*, Vol. 17 (1921), p. 275.

have advocated this type of oil migration. To test the plausibility of this theory, 200 cubic centimeters of oil were injected into the sand near the bottom of the glass aquarium. At the end of 10 days, there had been no measurable movement of the oil. A quantity of gas was then injected into the sand at the same point. There was some movement of the oil as long as the gas pressure was applied, but the migration stopped as soon as the pressure stopped. Much of the gas was also trapped in the sand. During the next 2 weeks there was no measurable movement of either the oil or the gas in the static water. At the end of 4 weeks, the oil had become so viscous that it could not be flushed out of the sand. W. L. Russell,[1] an advocate of the migration of oil through buoyancy, states:

> If the oil which first came through the seeps remained stationary, a mass of oil large enough to rise by bouyancy would finally accumulate. Hence, the migration of oil may be explained without the action of capillarity or hydraulic currents.

This statement implies that the greater the mass of oil, the greater the buoyancy of the mass. This is true, if the surrounding medium is composed entirely of water, or a similar liquid, but so far as has been observed, it is not true when oil migrates through a water-saturated sand. In such an instance, the nearer the globule of oil approaches the size of the pores, the easier will be its passage through the sand. It has been observed that in a dynamic system, a globule of oil will be broken into smaller globules or stringers so that passage can be accomplished through the sand. In a static system, the globules, both large and small, remain stationary until their viscosity has increased to such an extent that movement is impossible. H. G. Botset[2] has introduced evidence that proves, beyond doubt, that the viscosity of oil used in such experiments is increased through oxidation of the unsaturated hydrocarbons contained in the oil by exposure to the air. Exposure to the air would explain the increased viscosity of the oil, but its adhesion to the sand after a certain lapse of time is undoubtedly due to a chemical reaction between the oil and the sulphate radical found in fresh, connate, and sea water. This phase of the problem will be discussed in greater detail later.

The presence of the sulphate radical in connate or fresh water renders improbable the migration of oil through its buoyancy under static conditions. Thus far, in these experiments, no satisfactory accumulation of oil has been secured beneath an impervious cap rock.

[1] W. L. Russell, "Experiments in Capillarity," *Econ. Geol.*, Vol. 19 (1924), p. 52.

[2] H. G. Botset, "Permeability Measurements," *The Review of Scientific Instruments* (February, 1931), pp. 84–96.

POROUS CAP ROCK

SELECTIVE SCREENING[1]

If the impervious cap rock is to be discarded because it seems to require special subsurface conditions that are incompatible with the existing water-saturated substrata, the only alternative is to substitute a porous cap rock. It is difficult, however, to imagine a condition in which the sediments beneath the reservoir rock are porous and will permit free passage of both oil and water into the reservoir; but when these same liquids attempt to pass through the porous, overlying rock, a process of discrimination is begun which permits the water to pass, but retains the oil. Unnatural as the condition seems, capillary action may bring about some such condition of "selective screening," if there is enough difference between the porosity of the reservoir rock and the porosity of the cap rock. In other words, if the pores in the reservoir are larger than the pores in the cap rock, the water with its stronger surface tension could force its way into the overlying finer pores, and leave the oil behind in the reservoir rock. At least, theoretically, capillary action solves the puzzle of the porous cap rock, but what will the force of the circulating water do to capillary action?

CAPILLARY ACTION

In order to answer the foregoing question, it seemed desirable to exert more pressure on the apparatus than glass tubing could withstand. For that reason, apparatus of metal was constructed.

Since it was desirable to test the action of pressure on the capillary action of oil and water, equal quantities of the two liquids were placed in the container. To test the strength of the apparatus for the first time, a sand varying in size from 40 to 100 mesh was used. A much finer sand and clay were used later. To conform to the postulated water-saturated condition of the substrata, this sand was placed in the cup and thoroughly saturated with salt water. The sand was tamped tightly to reduce the size of the interstices. The cup was forced into the container, and then the apparatus was placed in a horizontal position, so that the separated oil and water might have equal access to the sand in the cup. Force was applied to the piston by a screw jack. At first, only water appeared, but when a quantity of water (approximately equal in amount to the water contained in the pores of the sand in the cup) had been squeezed out, oil also ap-

[1] John L. Rich, "The Hydraulic Theory of Oil Migration and Accumulation," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 7 (1923), p. 214.

peared. This experiment was repeated many times with various sizes of sand and clay. The smallest size used was 200 mesh. The result was always the same, first water, then oil and water appeared.

These results would seem to prove that capillarity could not effect a process of selective screening when pressure was applied. In spite of the fact that the results were so overwhelmingly against capillarity,

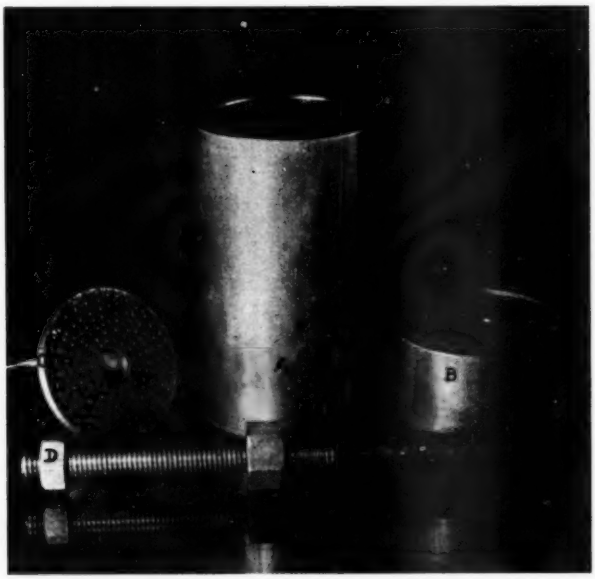


FIG. 4.—*A*. Hollow cylinder, 9×5 inches, to hold oil and water. *B*. Cup to hold sand and clay. It is inverted here to show perforated bottom. It fits tightly into cylinder. *C*. Perforated lid that fits inside top of cup and keeps sand or clay in place. *D*. Rod that passes through center of cup from top through bottom. Nut on right screws down tightly against lid, *C*. Nut on left end screws tightly against bottom of cup.

the obscurity that the use of metal apparatus naturally brings, left a feeling of dissatisfaction with the entire experiment. It was felt that if capillarity could not cause selective screening under high pressure, its failure to do so should be equally evident under a slight pressure, such as would be exerted by a 15-inch head of water. Glass apparatus could then be employed, and the results clearly observed.

To test this theory, a 12-inch length of 2-inch glass tubing was used (Fig. 5). The tube was tightly stoppered at one end; then fixed in a vertical position with the stoppered end down. A quantity of salt

water was poured into the tube. Fragments of rock were dropped in to serve as a very porous reservoir rock. The size of the fragments was gradually reduced until it was possible to add a coarse sand, then a finer sand, and finally, a dense ball clay. All the material was tightly tamped. After this, more coarse sand was added, then another layer of ball clay, another layer of sand, and a final layer of ball clay. The rock fragments and the layers of coarse sand represented three possible reservoir rocks, each capped with a fine-grained layer of white clay. All of the material was water saturated and tightly tamped. A 15-inch head of oil and water was used to drive the two liquids simultaneously into this arrangement of materials.

The oil and water at first passed easily into the apparatus, the balls and stringers of black oil sliding with serpentine ease between the rock fragments without friction, and apparently without actually touching the rocks. A film of water adhering to the rocks possibly acted as a barrier or lubricant[1] between the two.

After 3 days, the oil had penetrated the top layer of clay. Capillarity had again failed to act as a selective screen. Too much, possibly, had been expected of capillary action. If oil and water were being driven upward through the same capillary tube toward a cover rock, it is hardly reasonable to suppose that the driving force would fail to thrust both the water and oil with equal strength against the smaller pores of the cap rock. After that, if capillarity does act, it is probable that the superior surface tension of the water may assist any oil that has been thrust into the capillary opening ahead of it. Such may be the explanation for the failure of theoretical capillary action to perform a screening function for which it is not fitted, or which circumstances would not permit.

DIFFERENTIAL ADHESION

It has been stated before that, after 3 days, the oil had penetrated the top layer of clay; but during this time, the flow of water and oil into the sand had noticeably diminished. Two days later, the oil and water were only dripping from the overflow tube. There was no observable reason for this reduced flow; the oil that had accumulated in the rock fragments was still of the same color, and the rubber tubing, carrying the oil and water, was not clogged. The oil-water head was increased, and the outflow of liquid returned to normal, except that more water than oil passed through the apparatus, despite the fact that equal quantities of the two liquids entered the apparatus.

[1] Harold V. Dodd, "Migration of Oil," *Econ. Geol.*, Vol. 17 (1922), p. 281.

As hours passed, the outflow of liquid was again reduced. The outflow of oil had been much more reduced than the outflow of water. The relative quantity of water to oil was approximately 8 parts water to

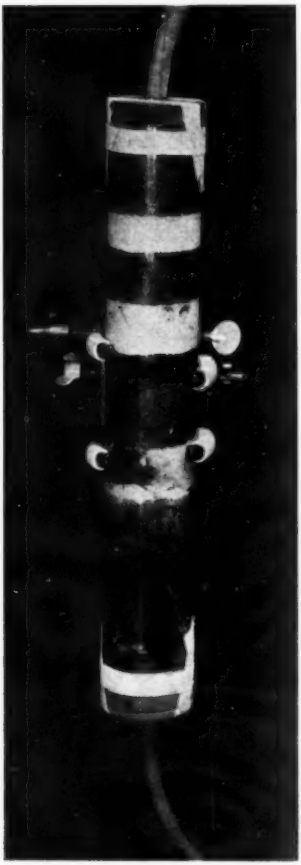


FIG. 5.—The three white bands are the porous cap rocks composed of white clay. Note the decreased oil content of the sands from bottom to top.

1 part oil. A close study of the three reservoir sands showed that the quantity of oil in storage in each had increased. The greatest increase was in the bottom reservoir, and the quantity diminished as the dis-

tance from the source of oil increased. There was no visual evidence of any sort of reaction between the oil and water; but that some mechanical or chemical reaction had occurred was the only satisfactory explanation for the phenomenon just described. Possibly there was some abnormal reason for it; possibly some unusual chemical in the water, or a reaction between the rubber tubing and the oil. A chemical analysis of the water showed it to be normal for surface water; the rubber tubing used was found to be unaltered. No factors, apparently, not associated with the accumulation of oil had entered into the problem.

Ten days later, both the water and oil had ceased to flow through the apparatus. An examination of the oil in the lower reservoir disclosed the fact that the oil no longer stood in clear, well-rounded drops. Their edges were blurred through adhesion to the rock fragments and to the inside of the glass tubing. The oil was removed from the lower reservoir so that it might be analyzed and a plausible explanation discovered for this reaction. It was found that the viscosity of the oil had increased, its water content had increased 6 per cent, and its Baumé gravity had decreased from 36.5 to 35.5. The increase in viscosity may have been due to the loss of some of the lighter constituents of the oil, or to a reaction between the oil and water, or to both. The increase in water content of the oil may have been due to an emulsion of oil and water, or to the absorption of the water film surrounding the rocks by the oil. The evidence was not clear that the oil absorbed the water film, but it is certain that the oil did, in some way, displace the water film and adhere to the rocks and sand. Both Dodd[1] and Mills[2] obtained somewhat similar results while following different procedures. They were, however, interested in other phases of oil migration and accumulation, and naturally did not interpret their results with reference to cap-rock control of oil accumulation.

This type of experiment was repeated a number of times to ascertain if oil exhibited this adhesive quality only in the presence of clay, or if it would react in the same manner with sand. The results led to the conclusion that the composition of the cap rock is of no material importance, except as it influences the size of the interstices. The oil will adhere to either sand or clay if given sufficient time. The time required to adhere to either material is approximately the same.

[1] Harold V. Dodd, "Migration of Oil," Experiment 7, *Econ. Geol.*, Vol. 17 (1922), p. 282.

[2] R. Van A. Mills, "Experimental Studies of Subsurface Relationships in Oil and Gas Fields," Experiment 3, *Econ. Geol.*, Vol. 15 (1920), p. 406.

FORMATION OF OIL POOL IN ANTICLINAL STRUCTURE

After these experiments, a desire was felt to observe how oil would accumulate through differential adhesion if the movement of the oil was not restricted by the sides of a vertical glass cylinder. An attempt was made to simulate the arching beds of an anticline inside the glass anticline, with varying grades of sand. The result more nearly approximated a sand lens on the crest of an anticline than a reservoir sand in a true anticline. It is believed, however, that the results would apply in either case. The sand in the glass anticline was first saturated with salt water, then oil and salt water were simultaneously forced into the apparatus through the under-arch opening. The oil entered the coarse sand lens and filled it nearly to the saturation point. Only a small percentage of the oil emerged through the overflow tube on the crest of the anticline.

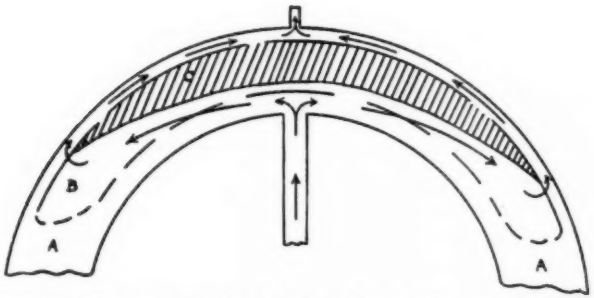


FIG. 6.—*A*. Fine sand. *B*. Dashes indicate outline of coarse sand lens. *C*. Hatched lines indicate accumulation of oil. Arrows show direction of flow of water around periphery of oil body.

The manner in which the oil accumulated in the reservoir sand is of interest. The first point at which accumulation began was in the very crest of the anticline at the point of contact between the reservoir sand and the cap-rock sand. As it became more difficult for the oil and salt water to penetrate the cap rock at this point, the accumulation gradually worked its way down the shoulders of the structure, but the point of accumulation always began at the contact between the reservoir sand and the cap rock. As the line of accumulation gradually progressed down the flanks of the structure, the quantity of oil at the first point of accumulation beneath the crest was continuously augmented through the cohesion of oil brought into contact with the static oil by the circulating salt water. A cross section of this oil accumulation would resemble the shape of a crescent moon. The accu-

mulation of oil on the flanks of the structure was below the water level of the oil accumulated beneath the crest of the structure.

At the end of 5 days, no more oil escaped from the crest of the structure through the overflow tube, but the salt water continued to flow. At this point, water dyed with indigo was forced into the apparatus in order that the path taken by the water to reach the overflow tube at the crest of the structure might be observed. It was found that the water flowed around the periphery of the sealed oil sand to reach the crest of the structure. It was also observed that the colored water did not penetrate into, nor flow through the lower part of the oil-saturated sand. This may indicate that the bottom of an oil pool is sealed sufficiently to offer resistance to encroaching edge water.

ACCUMULATION OF OIL ON TERRACE STRUCTURE

After the successful formation of an oil pool in an anticline beneath a porous cap rock, it was desirable to ascertain if the porous cap

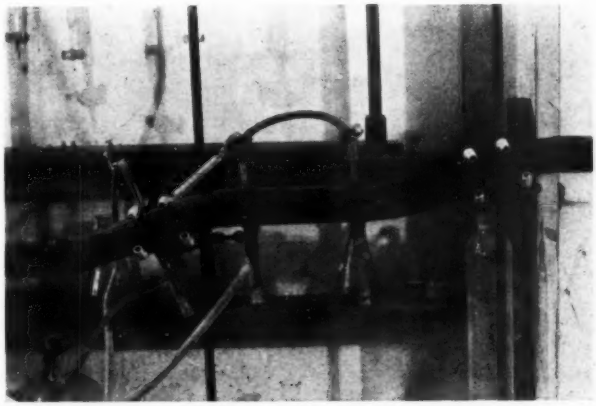


FIG. 7.—Terrace apparatus during experiment.

rock would also bring about an accumulation on a terrace. The picture shows how the terrace apparatus used in the former experiments with this type of structure was altered to fit the new requirements. The upper cap-rock layer of sand was composed of 150-mesh sand. The lower reservoir layer of sand was composed of 20-mesh sand.

Several experiments were performed with this apparatus, and all resulted in an accumulation of oil on the terrace in the same manner that an accumulation had been obtained in the anticlinal structure.

Some of the accumulations were large, others were small. The degree of success was directly proportional to the rate of flow and quantity of salt water permitted to enter the apparatus. If the water pressure was high, the oil could not accumulate and was flushed out of the upper end of the structure. If the water pressure was moderate enough so that the oil might accumulate and the cap rock become automatically sealed, the experiment was a success whether or not the oil and salt water were forced in beneath the dip or beneath the terrace. Any excess of oil migrated on up the dip. Here again, the amount of excess oil depended directly upon the quantity of water flowing through the lower part of the reservoir sand. The movement of the water through the lower part of the sand did not transmit motion to the oil accumulated in the higher part of the sand (this description applies to the movement observed after the cap rock was sealed), but there is a sharp line of demarcation between the oil and water below which no oil could accumulate. If the flow of water was increased after the oil had accumulated, the oil resisted the water movement, but the oil lying in the new path of the water was eventually flushed out of the structure.

CONCLUSION

The following explanation is offered for the phenomenon of oil accumulation beneath a porous cap rock. It is believed that the reaction (adhesion of the oil to the rock fragments and cohesion of the moving oil to the static oil), observed in the large interstices of the reservoir sand had also taken place in the small interstices of the clay cap rock. The size of the small drops of oil adhering to the inside of the interstices of the clay cap rock were augmented through cohesion with the oil that was brought into contact with it by the slowly moving water. In this manner, the interstices of the cap rock were gradually filled and the free passage of oil (but not water), prevented. Naturally, the entrance and exit of the water through the interstices of the cap rock was not as free as formerly, but it still had comparatively free passage, because of its greater liquidity, and because it did not adhere or cohere to the static oil or clay. This explains the fact that the volume of water passing through the cap rock was approximately eight times the volume of oil. The interstices, eventually, became so choked with oil that it was no longer possible for either oil or water to pass through. The cap rock was sealed through "differential adhesion."

The possible chemical nature of this differential adhesion process, and the possibility of the discovery of a similar or parallel process in the water-saturated substratum makes desirable a more extensive

consideration of this part of the experiment. Botset,[1] in a number of experiments, has shown that oil, passed through a filter in the presence of air, clogs the filter. If this same grade of oil is passed through the same type of filter in the presence of methane, the filter is not clogged. Botset attributes the clogging of the filter to the oxidation by air of the unsaturated hydrocarbons contained in the oil. He further substantiated this theory by showing that oil lacking unsaturated hydrocarbons does not clog the filter when passed through in the presence of air. The oil used in the experiments presented in this paper does contain unsaturated hydrocarbons; it has undoubtedly been oxidized through contact with the air. The fine-grained cap rock would act in the same capacity as one of the filters used in the Botset experiments. There is little reason to suppose that the oxidation of oil takes place on an extensive scale in the substrata, but there is sufficient cumulative data to indicate that there is a chemical reaction that takes place in the substrata between the oil and water, producing increased viscosity just as the oxidation of oil increases its viscosity.

G. S. Rogers is inclined to believe that the sulphate radical, which is present in both connate and meteoric water, has been reduced by reaction with the petroleum in the oil fields of the San Joaquin Valley. California. He appears to accept this view rather than account for the reduction of the sulphate through bacterial action, because, as he says,

> There is no evidence to show that even anaerobic bacteria can continue to exist in the muds after they have been covered by a thousand feet or more of other sediments and elevated into land, and certainly, some time must have elapsed after the elevation before meteoric water penetrated to the zone of alteration. In fact, the writer is inclined to believe that in some localities, meteoric waters are percolating down to this zone, and are being reduced at the present time. Hence, unless it be assumed that bacteria are present in the strata to depths of several thousand feet, the formation of the sulphate-free waters can not be ascribed to bacterial action.[1]

The waters associated with the oil in the San Joaquin Valley oil fields are almost, or quite, sulphate-free, notwithstanding the fact that the shallower waters of the region are characterized by a large concentration of sulphate. Continuing with this particular chemical reaction, G. S. Rogers states,

> Whatever the reactions controlling the character of the oil-field waters

[1] H. G. Botset, "The Measurement of Permeability of Porous Alundum Discs for Water and Oils," *The Review of Scientific Instruments* (February, 1931), pp. 84–96.

[2] *U. S. Geol. Survey, Bull. 653*, p. 96.

may be, it is clear that sulphide, free hydrogen sulphide, carbonate, bicarbonate, and free carbon dioxide are formed.[1]

He continues with one of the products of the sulphate reduction as follows,

As hydrogen sulphide readily oxidizes to sulphur, even under very feeble oxidizing conditions, considerable amounts of it are doubtless oxidized to sulphur, and so removed by precipitation from the waters.[2]

Later, in discussing the reaction of either a paraffine oil or an asphaltic oil with sulphur, Rogers writes,

A part of the sulphur may combine with certain oil constituents to form simple sulphur compounds or complex sulphur derivatives; another portion may unite with some of the hydrogen of the oil and pass off as hydrogen sulphide. By the loss of hydrogen a condensation or polymerization of the hydrocarbon molecules is effected, and this change is reflected in the increase in the gravity of the oil itself as it approaches solid asphalt.

In his conclusion, Rogers discusses field evidence in the area that has a direct bearing upon the results obtained through reduction of the sulphate radical.

The greatest proportions of carbon dioxide are usually found in gas near the outcrop where sulphate water can most readily enter the beds and where the reaction would naturally be vigorous. A large part of the hydrogen sulphide formed is probably changed to sulphur, some of which apparently reacts again with the oil to make it heavier and more asphaltic. It is significant that the oils containing the largest proportion of sulphur are, in general, the heavy oils close to the surface or to the outcrop of the oil measures.[3]

This absence of the sulphate radical in water associated with oil is not confined to California. Its absence in waters associated with oil has been noted in Europe and Asia, as well as in North America.[4]

These quotations from the work of Rogers have been presented to substantiate the theory that a cap rock may be formed through a differential viscosity resulting from the reduction of the sulphate radical.

The laboratory experiments recorded in the foregoing pages indicate the plausibility of the following statements.

1. It is impossible to secure an accumulation of oil in either anticlinal or terrace apparatus beneath an impervious cap rock (represented by glass in the experiments), if the reservoir sand is completely saturated with water.

[1] *Ibid.*, p. 100.

[2] *Ibid.*, p. 103.

[3] *Ibid.*, pp. 114–115.

[4] *Ibid.*, p. 94.

2. Oil will not migrate through buoyancy alone under static conditions. It is believed that the adhesion of the oil to the sand after the lapse of sufficient time was induced through the chemical reactions resulting from the reduction of the sulphate radical. This increased viscosity would prevent differential specific gravity from becoming active.

3. Oil migrates and accumulates under conditions that are dynamic. The term "dynamic" is used to denote a condition of movement inferior in activity to that condition of movement which is conceived to be denoted by the term, "hydraulic flushing."

4. Capillary action does not act as a selective screen that permits the escape of water through the cap rock and retains the oil in the reservoir sand.

5. The adhesive and cohesive properties of oil, increased by the chemical action resultant from the reduction of the sulphate radical, effectively seal the cap rock. "Differential adhesion" is suggested as the term to describe this method of cap-rock sealing.

6. The quantity of oil trapped in a reservoir sand by differential adhesion may be augmented by the cohesion of oil brought into contact with the static oil by circulatory water.

7. A crescent-shaped cross section may be the normal cross section of an anticlinal accumulation of oil. It is, however, necessary to take cognizance of the importance of such factors as the dip of the strata, the circulation of the subsurface water, individual structure peculiarities of sedimentation, the manner in which the oil is introduced into the structure, permeability of the strata, et cetera.

8. Water circulates around the periphery of a sealed anticlinal accumulation of oil.

9. With the same type of water conditions existing in the substrata as are postulated in these experiments, an accumulation of oil in a terrace structure is more susceptible to flushing by water than is an accumulation of oil in an anticlinal structure.

10. The factors that are of probable importance in the formation of an impervious cap rock by differential adhesion are: a. Pressure and rate of flow of the subsurface water. b. The percentage of the sulphate radical in the subsurface water. c. Chemical composition of the migrating oil. d. Size of, and nature of the interstices of the potential cap rock. e. Presence of joints, cracks, or faults in the potential cap rock. f. The thickness of the potential cap rock.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933). PP. 732-747

GEOLOGICAL NOTES

LONG BEACH, CALIFORNIA, EARTHQUAKE OF MARCH 10, 1933

The earthquake occurred at 5:54 Pacific time, Friday evening, and resulted in the death of 123 persons and the injury of several thousand others in and near the city of Long Beach, southern California. A greater tragedy was averted by the fact that the school children had left the scores of school buildings which partly or largely collapsed, and most factory and office workers had vacated other dangerous buildings. The shock was apparently not the heaviest of historic time in the general district, several in the past three centuries having seemingly been more severe, but the destruction was greater owing to the present heavily populated nature of the district. The first or main shock was felt for about 10 seconds, and after-shocks have now continued for several weeks, in general decreasing.

Because the earthquake originated along a structural line on which are a series of the world's more productive oil fields, and because the faulting which produced it also produced these reservoirs, a description of the structure may be of interest.

Figure 1 reveals the essential features. In the body of the map, the boundary faults are after Hoots,[1] Kew,[2] English,[3] and Findlay and Bode,[4] with some additions, The thumb sketch incorporates other work by Kew,[5] Loel,[6] Ellis and Lee,[7] and Eaton.[8] The central shear zone particularly discussed shows the work of the writer.

[1] H. W. Hoots, "Geology of the Eastern Part of the Santa Monica Mountains, Los Angeles County, California," *U. S. Geol. Survey Prof. Paper 165-C* (1930).

[2] W. S. W. Kew, "A Geologic Summary of California Oil Fields," *Oil Bulletin* (January, 1926).

[3] W. A. English, "Geology and Oil Resources of the Puente Hills Region, Southern California," *U. S. Geol. Survey Bull. 768* (1926).

[4] W. A. Findlay and F. D. Bode, "Structure of a Part of the San Joaquin Hills, Orange County, California," *Geol. Soc. Amer.*, Los Angeles meeting (April 8, 1933).

[5] W. S. W. Kew, "Geology and Oil Resources of a Part of Los Angeles and Ventura Counties, California," *U. S. Geol. Survey Bull. 753* (1924).

[6] Wayne Loel, unpublished map of the western Santa Monica Mountains, California.

[7] A. J. Ellis and C. H. Lee, "Geology and Ground Waters of the Western Part of San Diego County, California," *U. S. Geol. Survey Water Supply Paper 446* (1919).

[8] J. E. Eaton, "The By-Passing and Discontinuous Deposition of Sedimentary Materials," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 13, No. 7 (July, 1929).

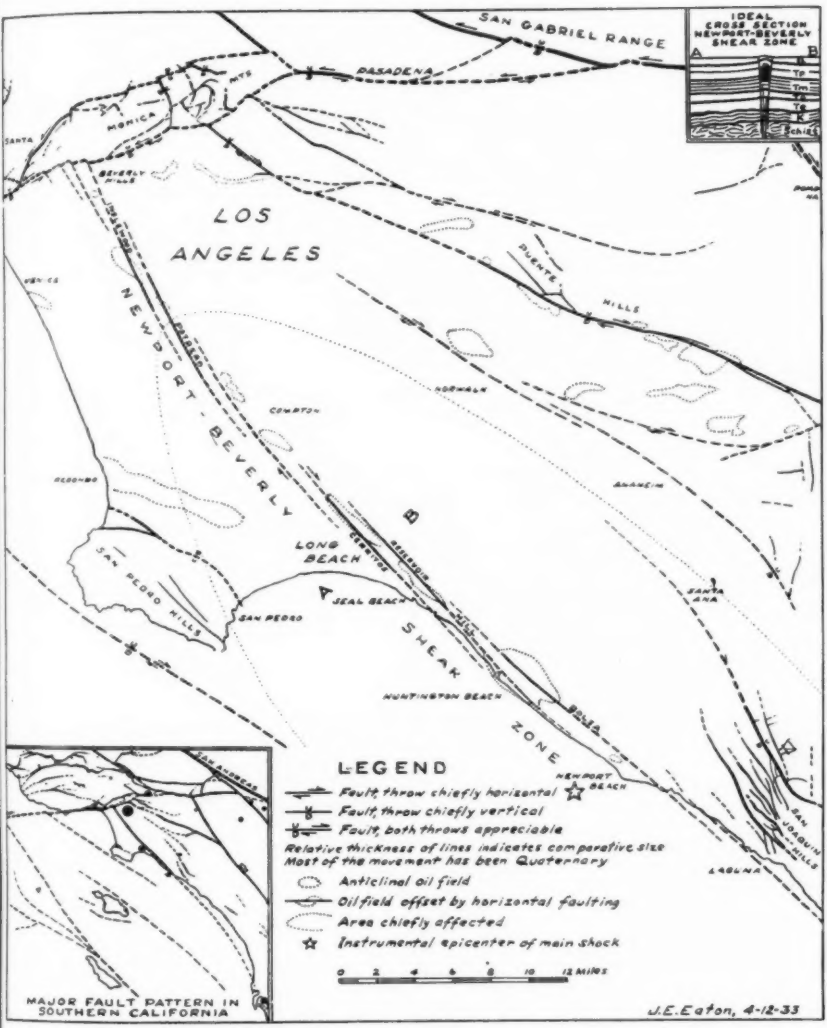


Fig. 1.—Fault map of northern Los Angeles Basin, showing region most affected. Larger blank areas are alluvium or sea covered, and presumably contain unmapped faults. Notice junction of northwest-striking series with that of east-west transverse chain. Deep-seated horizontal faults—long, comparatively straight fractures—are seismically most important. The major of these from east to west (see thumb sketch) appear to be the San Andreas, San Jacinto, Elsinore, Puente Hills, Newport-Beverly, Point Vicente, Santa Catalina, and San Clemente shears.

The Los Angeles Basin, near the center of which the disturbance occurred, reveals two sets of Cenozoic faulting, one bounding the basin with a combination of vertical and horizontal throws, and another cutting it with predominantly horizontal throws. A few of the faults can be traced back to the Miocene. The major throw on practically all is Pliocene and Pleistocene, chiefly the latter. Of the boundary faults, the frontal fault zone of the Santa Monica Mountains has several thousand feet of vertical throw and a horizontal throw of perhaps several miles, that of the San Gabriel Range locally 12,000 or more feet of vertical throw with a comparable horizontal component, while an axial fault in the San Joaquin Hills reveals 8,000 feet of throw reported to be chiefly vertical, and its probable extension near Santa Ana is shown by stratigraphic relations to have several thousand feet of throw which is also in the main vertical.

The second and in general younger set of faults cuts and offsets the series described. It is apparently of Quaternary origin, although parts of it may be older. The Benedict Canyon fault is mapped by Hoots as having a mile and a half of horizontal displacement, and along its unmapped extension north of Cahuenga Peak the writer has observed Monterey diatomite to abut against Temblor sandstone, indicating a moderate vertical throw. Other fault zones, such as the main one in the Puente Hills, have a dominantly horizontal component, shown variously by visible offsetting and *en échelon* arrangement of adjacent anticlines. The faults thus far referred to are on or near the edge of the basin, where compression has modified and in part obscured rotation.

Extending from Beverly Hills southeasterly to Newport Beach, diagonally across the basin, and then apparently onward under the sea as far as San Diego, is what is perhaps the most instructive and uncomplicated shear zone revealing rotational phenomena which is so far known to the geologic profession. The developing of nine almost evenly spaced oil fields along its anticlines arranged *en échelon*, five of which have contributed heavily toward flooding the world with oil, has bit by bit revealed the structure of this beautiful example. The writer[1] originally described this zone as follows.

> The Newport-Beverly . . . fault zone occupies a long and narrow strip extending like a scar from southeast to northwest across the basin. The structure extending from Newport to Beverly Hills is apparently dominated by a line of deep-seated faulting in consolidated rocks, this being evidenced by wells drilled, movements during historic time, and a characteristic topogra-

[1] J. E. Eaton, "Structure of Los Angeles Basin and Environs," *Oil Age* (January, 1924).

phy. The relation of the secondary structure to such deep-seated faulting is demonstrable by simple experiments with plastic substances. Although this faulting is known to reach the surface at certain localities, such surface expressions have relatively little in common with the anticlines along the uplift's strike, being, like these anticlines, secondary to deeper structure. The movements along this zone appear to have been largely horizontal, and to have occurred in almost straight lines in rigid material buried at great depth. The result of the . . . attendant drag has been the arranging of the more unconsolidated sediments near the surface into short folds at an angle to the deeper movement and *en échelon*. . . . This horizontal faulting in the basement rocks . . . is probably the result of crustal adjustments which have resulted in a relative movement of the basin from southeast to northwest along the coast, and from northwest to southeast upon the landward side.

Later discoveries agree with the essential portions of this early thesis. Horizontal movement of coastal California northwesterly is known from the work of Noble,[1] which has been corroborated by the writer,[2] 24 miles horizontal displacement of Miocene formations along the San Andreas rift having been measured at two separated localities, at a third locality Miller[3] reports 16 miles of gneiss to abut against an equal length of schist along the rift, and Reed[4] suspects at least as large a displacement from the relation of granitic boulders to their most obvious source.

Further work along the Newport-Beverly shear zone has caused the writer to elaborate on certain of his early conclusions. More detailed investigation shows the deep-seated, hidden shear to be expressed at the surface by at least five, and more probably seven secondary fractures arranged *en échelon*, and if the southern portion buried beneath the sea is considered, the total number of surface fractures may exceed a dozen. These secondary faults or tension cracks deviate clockwise, and the associated anticlines counter-clockwise,[5] from the strike of the deep-seated shear, as is apparent on Figure 1. The surface fractures do not join, but are separate lines which overlap, and which die out as they do so. They have moderate vertical components of not more than a few hundred feet, and there

[1] L. F. Noble, "The San Andreas Rift and Some Other Active Faults in the Desert Region of Southeastern California," *Carnegie Inst. of Washington Year Book 25* (1925–26).

[2] J. E. Eaton, "Notes on the Principle and Theory of Isostasy," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 12, No. 12 (December, 1928).

[3] W. J. Miller, discussion, *Geol. Soc. Amer.*, Los Angeles meeting (April 7, 1933).

[4] R. D. Reed, "Santa Margarita Conglomerate of the Temblor Range," *Geol. Soc. Amer.*, Los Angeles meeting (April 7, 1933).

[5] J. E. Eaton, "Decline of Great Basin, Southwestern United States," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, No. 1 (January, 1932), Fig. 8.

are indications that some of them scissor, the downthrow being on one side for a part of their length, and then crossing over to the other side. In a word, there is apparently not a single fault at the surface, but a series of disconnected, overlapping tension cracks arranged *en échelon* which pass on to one another, like a chain, the task of relieving the strain set up by the deep-seated shear.

The zone was regarded for a number of years as a continuous fracture on the surface, and was so delimited on maps, with the result that various local names have been applied to it. Among these, in the approximate order of their priority, have been the names Signal Hill, Palms, Inglewood, Huntington Beach, and Dominguez, according to the varying interests of investigators. The term Inglewood has of late years been in use among seismologists, due to an earthquake at that locality. The common failure to use the ending "zone" when using the name of local fractures to designate the whole, causes the superficial and the primary feature designated by the same term to be confused, and obscures the true mechanics. Until the fundamental difference between the short tension cracks and the underlying shear is thoroughly understood, the writer will call the whole the Newport-Beverly shear zone from its two landward extremities.

That the general zone has had approximately a mile of horizontal throw since the Miocene is indicated by the feature that in at least three oil fields Pliocene sands seem to be offset some such amount. Beyond the northwest end of the zone the upper Miocene sediments near Beverly Hills have the appearance of being offset, but this is probably more apparent than real, since the shear only doubtfully crosses the transverse Santa Monica Mountains fault zone as a unit, and more probably is diffused after reaching the latter. Of more significance is the feature that the transverse fault zone south of the Miocene outcrop is offset approximately a mile, as shown by the fact that the transverse range is offset that distance in the general vicinity of the place where the shear zone intersects it. The great transverse chain recognized by Blake[1] disorganizes the northwest-striking shear, and apparently prorates its throw throughout a 6-mile bend in the range front (a gradual offset) between Sherman and Brentwood Park. The western limit of the main granitic batholith, suggested by the western limit of contact metamorphism, forms a line of weakness which would invite the Newport-Beverly shear zone to head there. The shear veers at Dominguez Hill and strikes for this contact, which has been a place of weakness since the middle Miocene,

[1] W. P. Blake, "Pacific Railroad Reports," *U. S. War Dept.*, Vol. 5, Pt. 2 (1856).

as shown by a freakish local deposition of upper Miocene sediments, and their preservation.

Horizontal movement along the deep-seated shear has been largely absorbed by the *en échelon* folds, it being demonstrable that surface folding of this nature can absorb considerable horizontal throw. The secondary, disconnected surface fractures tend, by their *en échelon* arrangement, to transmit some of the differential movement to outer areas of plastic sediments, and these have absorbed portions of it by gentler folding than occurs along the axis. With sufficient movement, or a thin enough blanket, a horizontal shear would break through to the surface in a narrow band. In the present instance the magnitude is inadequate to overcome the very thick plastic covering, and what is probably a single throw at depth is dissipated upward into *en échelon* folds and broad marginal warps, accompanied by secondary tension cracks. The hidden shear theoretically passes beneath the series of anticlines, and not on one side as drawn on early maps.

The earthquake discussed occurred along the central part of the shear zone. Since the damaged area is elongate, the shear presumably slipped over a considerable distance. A rough and unqualified measure of the area over which slippage occurred is the difference in length between the two axes, which indicates that the shear slipped throughout about 30 miles of its length. The tension cracks above the deep-seated shear would not necessarily immediately move in sympathy, since the upper adjustment is chiefly by folding, but would tend to grind their plastic walls almost imperceptibly throughout a period of years.

Gianella and Callaghan,[1] reporting on a widely felt disturbance in the Great Basin, showed a crustal movement there of southeast parts toward the northwest, or similar to that along the Newport-Beverly shear zone, and found resulting surface fractures to tend to lie *en échelon* and to deviate clockwise from the axis of the disturbance, as would follow from the conditions. They report that of 70 after-shocks felt by them on a certain day near the epicenter, none was recorded by a seismograph 125 miles distant, although a more sensitive instrument at approximately the same distance recorded several. Gutenberg[2] states that the epicenters of these after-shocks varied as much as 50 miles. He informs the writer that tentative figures indicate that the epicenters of the Long Beach earthquake after-shocks varied from 5 to 10 miles along the strike of the shear zone.

[1] V. R. Gianella and Eugene Callaghan, "Cedar Mountain, Nevada, Earthquake of December 20, 1932," *Seis. Soc. Amer.*, Los Angeles meeting (April 8, 1933).

[2] B. Gutenberg, oral communication.

The after-shocks of the Great Basin earthquake seem, by their merely local significance, to reveal secondary adjustment along secondary surface fractures. The Long Beach earthquake after-shocks, on the other hand, some of which were perceptible to the writer while in Santa Barbara, 108 miles from their epicenters, would seem to indicate chiefly further slippage of the original, deep-seated shear. The unexpectedly small damage to oil wells along the shear zone, most of which are a mile or more deep and lie almost astride of the epicenter, indicate that the secondary surface fractures which pass by, between, and through these wells did not move appreciably.

Reference is again made to Figure 1. A majority of the faults plotted thereon are active, in the sense that most of them have moved in Recent time; that is, during the last 10,000 or 20,000 years. It is safe to conclude that no area in southern California will be free from earthquakes. Considering the rarity of perched rocks and pedestals, and the almost entire absence of certain cliff types normal to less disturbed regions, it is equally safe to conclude that shocks stronger than any recorded in historic time will occasionally visit each part of California. One of the hardest things of which to convince the public and its political guardians is the fact that in a region geologically expressing recent strong seismic activity an historic dearth of earthquakes is not a favorable, but an ominous sign. However, the risk of death or injury from earthquakes is relatively small. According to current statistics, the average person in California has many times as much chance of dying in an automobile accident as in the appreciable earthquake which each average part of California can expect at intervals of perhaps a hundred years or so. The wisest plan would seem to be to admit the susceptibility, and to work for safer construction of buildings. It is in this spirit that the meeting of the Seismological Society of America held April 8, 1933, agreed, without dissent, that southern California can expect at unknown future times more earthquakes and stronger ones[1] than that herein discussed. This reflects the opinion that the interests of public safety require a frank and unequivocal reading of the record that is written in the rocks.

J. EDMUND EATON

NORTH HOLLYWOOD, CALIFORNIA
April 14, 1933

[1] Statement by H. O. Wood, concurred in by J. P. Buwalda.

CRACKS PRODUCED BY LONG BEACH, CALIFORNIA, EARTHQUAKE

The accompanying picture shows one of two cracks that were produced in a field ½ mile southwest of the intersection of Olive and Atlantic boulevards, on the eastern outskirts of Compton during the recent southern California earthquake. The length is 6 feet and a stick could be pushed down about 5 feet. Being in an artesian area,

Fig. 1.

water flowed from the crack as soon as it was formed and for a short time afterward.

The fact that each of the two cracks trends approximately N. 45°W. might be explained by tension which a compression wave caused when it momentarily distorted the earth. The tension would normally cause cracks paralleling the radii of the seismic wave. The epicenter was located about 2 miles west of Newport Beach under the

Pacific. As the position of these cracks is northwest from the epicenter about 10 miles, their direction does parallel the radii of the seismic waves.

After the passing of the compression wave, the unconsolidated sand, lacking elasticity, failed to return to its original position, thus leaving the cracks. The same explanation suffices for a series of cracks which have been reported in the vicinity of Compton, with a northeast-southwest trend.

If a circular disc of rubber were stretched to increase its circumference, one would note tension paralleling the radii and also paralleling the circumference. The momentary expansion in a circular block of the earth's crust outlined by a seismic wave at a given instant would represent a state comparable with the stretched circular disc of rubber. The tension that developed parallel with the radii of the waves could explain cracks such as the one in the picture and tension parallel with the seismic waves could explain the cracks reported in the same general area, at right angles to the one shown.

DONUIL HILLIS

LOS ANGELES, CALIFORNIA
May, 1933

PROJECTION OF DIP ANGLE ON PROFILE SECTION

A profile section which crosses the strike of stratified formations will show foreshortened angles of dip, unless the section happens to be perpendicular to the strike. In fact, the actual angle to be placed on a section for the purpose of representing the dip is very easily computed in any case. Thus: ***the tangent of the actual angle is equal to the tangent of the dip angle multiplied by the sine of the angle which the line of profile makes with the line of strike.***

In the accompanying drawing (Fig. 1) the horizontal and vertical reference planes, and likewise the plane of the formation, are shown to intersect along the strike of the formation. θ is the angle of dip of the formation. The plane of the profile and its line on the horizontal plane are also shown. ϕ is the angle which this plane makes with the vertical plane; consequently, it is the angle which the line of the profile makes with the strike of the formation. α is the angle which is to be constructed on the plane of the profile for the proper representation of the formation in its dip.

At a point where the plane of the profile intersects the plane of the formation, the line a is drawn perpendicularly to the horizontal

plane. It lies, of course, on the plane of the profile. The point at the foot of this line lies at a distance c from the intersection of all four planes. From this same point the line b is drawn perpendicularly to the strike.

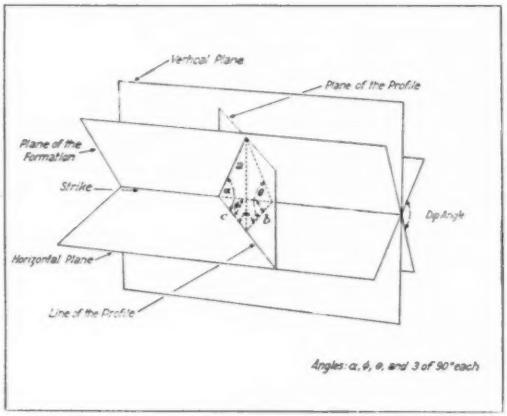


Fig. 1.

Now we have the following equations:

$$\frac{a}{b} = \tan \theta \tag{1}$$

$$\frac{b}{c} = \sin \phi \tag{2}$$

$$\frac{a}{c} = \tan \alpha \tag{3}$$

From (1):

$$a = b \tan \theta \tag{4}$$

From (2):

$$c = \frac{b}{\sin \phi} \tag{5}$$

The substitution of (4) and (5) into (3) gives:

$$\tan \alpha = \tan \theta \sin \phi \tag{6}$$

A table of natural tangents and sines will provide the required numbers.

The table of logarithmic tangents and sines offers a simplifica-

tion in the fact that, with respect to the two terms on the right, the process of addition replaces that of multiplication, for

$$\log \tan \alpha = \log \tan \theta + \log \sin \phi \qquad (7)$$

The angle α is read directly from the table of logarithmic tangents.

STANLEY C. HEROLD

LOS ANGELES, CALIFORNIA
March 6, 1933

Mr. Herold's ingenious solution of the problem is very interesting. The equation may be solved conveniently by graphs with a degree of accuracy sufficient for ordinary work. The accompanying graph is submitted as an example (Fig. 2).

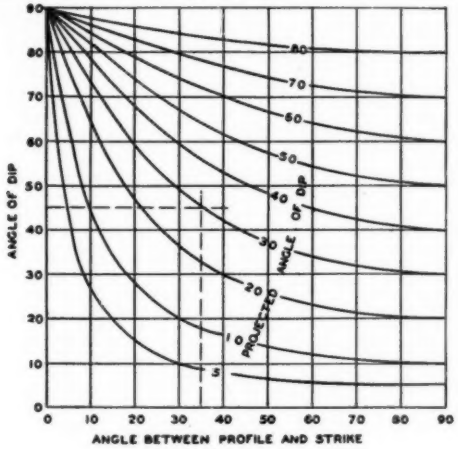


Fig. 2.

A solution of a problem is indicated by the dashed lines. Let us suppose we are drawing a profile section at an angle of 35° to the strike of the beds. The beds dip at an angle of 45°. The projected dip angle on the plane of the section will be 30°.

Using Mr. Herold's formula, the solution is as follows.

$$\tan \alpha = \tan \theta \sin \phi$$
$$\theta = 45^\circ$$
$$\phi = 35^\circ$$
$$\sin 35^\circ = \quad .57358$$
$$\tan 45^\circ = 1.00000$$
$$\tan \alpha = \quad .57358$$
$$\alpha = 29^\circ\ 50'$$

TULSA, OKLAHOMA
May 4, 1933

LYNDON L. FOLEY

SUGGESTED RESEARCH ON ORIGIN OF PETROLEUM

It is generally recognized by petroleum geologists that petroleum and natural gas have been generated from the fatty remains of marine animals and the gelatinous, fatty, resinous and waxy parts of plants. However, the data bearing on the nature of the transformation are inadequate and unsatisfactory.

The recent comprehensive studies of modern sediments by Trask have revealed interesting information bearing on the subject, although much work remains to be done. It should be borne in mind that his samples were obtained from the surface of the deposits or from relatively shallow depths in them and that probably no great length of time had elapsed between the accumulation and the collection of the material. If a method of sampling could be devised whereby it would be possible to secure material from a greater depth in the sediments, the results might be more enlightening.

In connection with this baffling problem of the origin of oil and gas, it occurs to the writers that experimentation under controlled conditions during a long period of years, with plant and animal matter capable of serving as source materials, might yield valuable information which would supplement the interesting data assembled by Trask. The purpose of such an investigation would be to determine not only the rate of transformation of source material into oil or gas or an intermediate product, but also the nature of the reactions involved and the possible rôle of anaerobic bacteria in the process.

A suggested line of procedure involves the placing of organic matter of several types in compartments of a suitable chemically inert container so designed as to permit restricted circulation of water but to retain and protect the contents from scavengers and to trap any oil or gas, or both, generated. This should be submerged and anchored in the sea under favorable environmental conditions. At periodic intervals the container might be raised sufficiently near the surface to permit the removal of portions of the several samples and their decomposition products for laboratory study without exposing the remaining contents to the atmosphere. The duration of the periods between sampling should be a function of the duration of the investigation and the rate of transformation of the organic debris as determined in the early stages of the experiment.

For the best results, plans should be made to conduct the study for as long a period as justified by the results obtained and under more than one environmental condition. The supervision of the experiment should be in the hands of a group of scientists including a petroleum geologist, a bacteriologist, and an organic chemist. Some permanent

organization interested in marine biology such as the Marine Biological Laboratory at Woods Hole, Massachusetts, should be able to coöperate in a study of this kind at a minimum of expense and a maximum of efficiency.

F. M. VAN TUYL
BEN H. PARKER

GOLDEN, COLORADO
April 17, 1933

KINCAID FORMATION, NAME PROPOSED FOR LOWER MIDWAY OF TEXAS[1]

The name "Myrick" was proposed by Vaughan[2] to cover all the deposits in southern Uvalde County from the top of the Upper Cretaceous to the gravels. Beds later mapped as Midway, Indio, Carrizo, Bigford, and Mount Selman, were included. Unfortunately such a name is too comprehensive, and Kincaid, from the Kincaid ranch in southeastern Uvalde County, is here submitted for the beds in Texas overlying the Cretaceous and overlain by the upper Midway, or Wills Point formation. Vaughan's name "Myrick" was taken from "Myrick's apiary," 12 miles (air line) east-southeast of Uvalde, which stood and still stands on the high Frio River bank commanding a view of the most complete section of the lower Midway exposed in the state of Texas. The exposure from the Cretaceous contact, ¾ mile above the apiary, to the Wills Point contact, ¼ mile below it, may serve as the type of the Kincaid formation. The outcrops of the Kincaid are repeated downstream and are continued to within about a mile of the old Kincaid ranch-house. The Brazos and the Colorado offer finer sections of certain horizons, but only the Frio offers a scarcely interrupted outcrop of the entire lower Midway from the Escondido to the Wills Point.

Figure 1 may serve to fix the section geographically. It is taken with slight alterations from the topographic sheet, which unfortunately does not indicate the course of the Frio with perfect accuracy.

The Uvalde Folio, published by the United States Geological Survey in 1900, is no longer available for distribution and it may be well to repeat the section which has given to the Midway of this area so great a historic interest. In that folio Vaughan wrote, under his discussion of the "Myrick formation":

[1] Published by permission of the director, United States Geological Survey.

[2] T. Wayland Vaughan, *U. S. Geol. Survey Uvalde, Texas, Folio 64* (1900), pp. 2–3.

The stratigraphic relations existing between the Eocene and Cretaceous deserve special consideration. The contact between the two series is seen at the locality 2 miles below Engelmann's ranch,[1] and about half a mile (in a straight line) above Myrick's lower apiary.[1] As much as the Texas Eocene and Cretaceous have been studied, only one actual contact had been previously found; this gives the contact on the Frio an especial interest and importance.

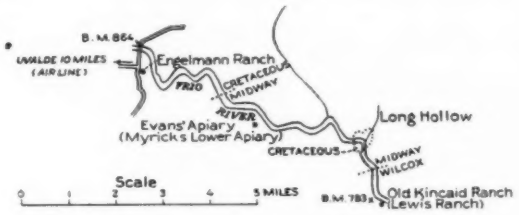


FIG. 1.—Frio River, southeastern Uvalde County, Texas.

The following is the description of a section across the contact.

SECTION ON FRIO RIVER ALONG EOCENE-CRETACEOUS CONTACT

	Feet	*Inches*
7. Rather soft yellowish sandstone. An interesting lithologic feature of this sandstone is the occurrence in it of large oval sandy nodules, which stand with their long axes vertical. They range from 1 foot to 1 foot 6 inches in length, and vary between 3 and 7 inches in diameter. Some of these nodules, by breaking across, form sandstone disks. Some nodules are more nearly globular	22	6
6. Soft, yellow, sandy clay, with bluish streaks; some small pebbles in lower part	2	6
5. Nodules of glauconitic sandstone. These contain a considerable number of small pebbles. In lower few inches of this layer a considerable number of *Ostrea cortex* Conrad are found. This layer is principal horizon of large new species of *Nautilus*		6
4. Soft, very argillaceous, yellow sands, quite glauconitic. There is a ledge of *Ostrea cortex* near top of this layer; also a *Turritella*, probably *T. trilira* Conrad, was found in it. This stratum is uppermost horizon of Cretaceous	4	6
3. Harder sandy claystone, whitish blue or yellowish in color	1	4
2. Soft yellow, sandy clay	8	8
1. Sandstone, originally bluish, oxidizing brown and containing fucoidal impressions. Upper part of this stratum becomes softer, is more yellowish, and is in rather thin layers	11	9
Total	51	9

Beds 7–5 are Eocene [Kincaid], and 4–1 are Cretaceous.

A short distance downstream from this exposure, both opposite and above Myrick's lower apiary, the *Nautilus* found in stratum No. 5 is associated with such typically Eocene species as *Turritella mortoni* Conrad, *Cucul-*

[1] This ranch is still in the Engelmann family but "Myrick's lower apiary" is now (1933) the Bob Evans apiary. Julia Gardner.

laca saffordi (Gabb), etc. There is no doubt that stratum No. 5 is Eocene, and that stratum No. 4 is Cretaceous.[1]

The "soft yellowish sandstone" of Bed No. 7 thickens to 30 or 35 feet downstream with an additional 10–15 feet indicated in the higher ground back from the banks, but it is probable that the total thickness of the Kincaid in the Frio River section does not exceed 100 feet. Glauconite is a fairly constant but not abundant constituent and the calcite content is locally sufficiently high to indurate the layers so that they stand out as resistant ledges which may be followed for considerable distances both above and below the apiary. There is a slight interruption in the exposure upstream from the apiary, but just above the trail leading down from the apiary, the higher beds of the Kincaid, which are not represented in the Vaughan section, crop out as a dense glauconitic limestone, gray where unweathered and forming a prominent ledge which is above water only when the river is low. The general assemblage of the common but poorly preserved fossils suggests the "Second Greensand" of Caldwell and Bastrop counties. This ledge can be followed downstream for $\frac{1}{8}$ to $\frac{1}{4}$ mile where it forms the base of a bluff of about 50 feet at the maximum. In this bluff, limestone is overlain by 10–20 feet of gray sands and clays containing rounded concretions, some of them 2 feet in diameter. These sands and clays have been referred to the Wills Point (upper Midway), and they are overlain with marked unconformity by heavy cross-bedded sands of Indio age.

Downstream from the apiary, the lower Midway section is repeated as the result of a structural uplift and $\frac{1}{4}$ to $\frac{1}{2}$ mile above the mouth of Long Hollow, the Escondido is brought to the surface by the same uplift, and persists as a ridge on the east side of the channel for a distance of 100–150 feet. The Escondido is also present in the east bank of the Frio. I have Frank Getzendaner's generous interest to thank for directing me to an excellent contact exposed in the break designated as Long Hollow on the topographic map, although there is no stream draining it and the indentation does not exist for more than $\frac{1}{8}$ mile.

The following section is exposed on the southeast bank of the arroyo.

	Feet	*Inches*
8. Arenaceous limestone, fossiliferous and glauconitic	6	0
7. Yellow sand, slightly glauconitic	4	6
6. Arenaceous, sparsely glauconitic, and fossiliferous limestone	1	8
5. Fine yellow, slightly glauconitic sand	1	6

[1] T. Wayland Vaughan, *Geologic Atlas of the United States, Uvalde Folio 64* (1900), p. 2.

4. Indurated, highly calcareous, glauconitic sandstone, resistant and ledge-forming	1	0
3. Fine yellow, slightly glauconitic sand	2½–3	
2. Basal conglomerate forming a discontinuous series of boulders, abundantly glauconitic and very hard and pebbly. *Enclimatoceras* 2 feet above base	2	6
Unconformity		
1. Yellow fucoidal sandstone. *Ostrea cortex* was not observed but *Sphenodiscus* was found apparently worked out from clays in bottom of hollow	10	0

Bed No. 1 is referred to the Escondido; beds 2 to 8 to the Kincaid formation of the lower Midway.

The indurated calcareous sands and sandy limestones are resistant and ledge-forming, particularly that of bed No. 8, although they are not continuous with the similar beds in the apiary section. The manner in which these hard layers may lose their identity, becoming more arenaceous, less indurated, and tending to fuse not only with one another but with the intermediate sands, may be clearly observed along the southwest bank of the Frio a little less than a mile below the apiary. Downstream from Long Hollow along the east bank of the Frio and at the final outcrop about 1 mile above the Kincaid Ranch house, there is at least one bed and there are usually 2 or 3 sufficiently resistant to form prominent ledges. Most of the sandy limestones or calcareous sandstones are fossiliferous, some of them abundantly so, although the fossils occur in a very poor state of preservation. They are commonly characterized by the brown calcite of the large, thick-shelled bivalves and are probably the equivalent of that designated the "Squirrel Creek" limestone by Liddle in his Medina County report.

The north line of the Kincaid Ranch falls, according to a written communication of the Garner Abstract Company of Uvalde, about 15,000 feet above the old ranch house. The name Kincaid was chosen because among those associated with Frio River in its course through the Midway area of outcrop it seems the best available. The family has been and still is prominent in the history of Uvalde County, the "Red" Ranch house is a landmark, and the name Kincaid is reasonably short and has a certain individuality that inhibits confusion with other formation names.

UNITED STATES GEOLOGIST SURVEY
WASHINGTON, D. C.
March 27, 1933

JULIA GARDNER

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6, (JUNE, 1933), PP. 748-749

REVIEWS AND NEW PUBLICATIONS

"The Lower York-James Peninsula." By JOSEPH K. ROBERTS. *Virginia Geol. Survey Bull. 27*, Educ. Ser. 2 (1932). 58 pp., 21 pls., 7 text figs.

The peninsula between York and James rivers in Tidewater, Virginia, is justifiably characterized as the Cradle of the Republic. Of the eight counties included, six were settled in 1634; Jamestown, settled in 1607, was the first permanent English colony; Williamsburg, the old Colonial capital, is said to be the oldest incorporated town in the country and there, in 1693, the College of William and Mary was founded. General Benjamin Lincoln, in 1783, wrote "An Account of Several Strata of Earth and Shells on the Banks of York River, in Virginia," which he published in the *Memoirs of the American Academy of Arts and Sciences*, Vol. 1, a tribute not only to the exceptional outcrops offered by the York but also to the interest in natural history among the pioneers of that section. Collections from the splendid exposures of the Tertiary formations along the York and the James were made by or were known to all of the early Tertiary paleontologists and geologists of the middle Atlantic seaboard,—to Conrad, and Lea and Finch, and Lyell. Doctor Roberts has concerned himself with only the four counties at the lower end of the York-James peninsula. In this bulletin, written primarily for field classes, he has assembled the significant geological features, topographic, stratigraphic, and paleontologic, against their colonial background. It is interesting to know that the fortifications at Yorktown are from the same coquina which has aroused the enthusiasm of the collectors of fossils. It is interesting, too, that in the Rockefeller project, the materials from which they are making their hand-made bricks are those from which most of the colonial brick structures were made.

The illustrations are excellent. Some of the best of the topographic maps and airplane photographs of the area have been reproduced and 30 of the typical Yorktown fossils have been briefly characterized and adequately figured. The bulletin will be a necessary item in the equipment of the paleontologist who goes collecting along the lower York-James and will add very greatly to the interest of the tourist's pilgrimage.

JULIA GARDNER

UNITED STATES GEOLOGICAL SURVEY
WASHINGTON, D. C.
May 1, 1933

RECENT PUBLICATIONS

CALIFORNIA

"Jurassic and Cretaceous Divisions in the Knoxville-Shasta Succession of California," by Frank M. Anderson. In *Mining in California*, July and

October, 1932 (April, 1933), pp. 311–28; 5 figs. This issue includes 2 quarterly chapters of Report 28 of the State Mineralogist (Ferry Building, San Francisco). Price, $0.50.

California Oil Fields (San Francisco), Vol. 17, No 4 (April, May, June, 1932), issued in May, 1933, contains the following special articles.

"Subsurface Storage of Oil and Gas in the Brea-Olinda and Lompoc Fields," by F. C. Hodges and A. M. Johnson, pp. 5–12.

"Lompoc Oil Fields, Santa Barbara County," by S. G. Dolman, pp. 13–19.

GEOPHYSICS

"Theory of Torsion Balance, with Preliminary Study of Modification of Instrument to Decrease Time of Gravity Measurements," by J. W. Joyce. *U. S. Bur. Mines Tech. Paper 546* (1933). 46 pp., 21 illus. Price $0.05.

Colorado School of Mines Quarterly (Golden, Colorado), Vol. 27, No. 3 (July, 1932), contains the following.

"Announcement of the Series of Publications of the Department of Geophysics," by C. A. Heiland, pp. 5–9.

"A Study for the Development of a Field Magnetometer Based on the Principle of the Earth Inductor," by Pedro I. Aguerrevere, pp. 11–29; 6 figs.

"A Magnetic Survey of the Ralston Dike, Jefferson County, Colorado," by William S. Levings, pp. 31–41; 6 figs; 2 pls.

"Study of an Adjustable Wave-Filter Suitable for the Reception of Reflected Seismic Waves," by Sylvain Pirson, pp. 43–64; 20 figs.

GERMANY

"Bitumenspuren im Schwäbischen Mittleren Muschelkalk und die Frage ihrer Bedeutung" (Traces of Bitumen in the Schwabian Middle Muschelkalk and Their Significance), by Rudolf Wager. *Kali, Verwandte Salze und Erdöl* (Potash, Related Salts and Petroleum), Vol. 27, No. 7 (April 1, 1933), pp. 79–84; 4 figs. Wilhelm Knapp, Halle (Saale), Mühlweg 19, Germany.

LOUISIANA

"The Contribution of Louisiana State University to the Development of Louisiana Geology," by Henry V. Howe and Cyril K. Moresi. *Louisiana Conservation Review* (New Orleans), Vol. 3, No. 2 (April, 1933), pp. 23–33; 1 fig. Historical; lists geologists of various state surveys and their publications.

TURKEY

"Bibliography of Geology and Mineral Resources of Turkey." *U. S. Bur. Mines* (Washington, D. C.). Mimeographed copies available free.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), PP. 750-751

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for membership in the Association. This does not constitute an election, but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to J. P. D. Hull, business manager, Box 1852, Tulsa, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Roy La Mont Ginter, Tulsa, Okla.
W. B. Wilson, L. L. Foley, Robert H. Dott

E. B. La Rue, Athens, Tex.
Ben C. Belt, H. E. Minor, E. G. Thompson

Burton Armand Lilienborg, Tulsa, Okla.
A. I. Levorsen, L. L. Foley, Kent K. Kimball

Ian Campbell Low, Buenos Aires, Argentine, S. A.
Frank B. Notestein, John O. Bowers, George A. Severson

Leland R. MacFarland, Oklahoma City, Okla.
R. J. Riggs, John E. Van Dall, William W. Clawson

Ellen Posey, Bartlesville, Okla.
A. F. Morris, V. E. Monnett, Charles E. Decker

Henry Dayton Wilde, Houston, Tex.
John R. Suman, Wallace E. Pratt, L. T. Barrow

FOR ASSOCIATE MEMBERSHIP

Edward Lain Howard, Tyler, Tex.
F. S. Prout, Wallace C. Thompson, Jack M. Copass

Roy Livingston Lay, Houston, Tex.
L. A. Scholl, John C. Miller, Frank C. Adams

James H. McCourt, Cut Bank, Mont.
J. S. Irwin, John G. Bartram, J. E. Hupp

Fredrick W. Mueller, College Station, Tex.
John T. Lonsdale, Frederick A. Burt, B. Coleman Renick

ASSOCIATION COMMITTEES

EXECUTIVE COMMITTEE

FRANK R. CLARK, *chairman*, Mid-Kansas Oil and Gas Company, Tulsa, Oklahoma
WILLIAM B. HEROY, *secretary*, Sinclair Exploration Company, New York, N. Y.
FREDERIC H. LAHEE, Sun Oil Company, Dallas, Texas
GEORGE SAWTELLE, Kirby Petroleum Company, Houston, Texas
L. C. SNIDER, H. L. Doherty and Company, New York, N. Y.

GENERAL BUSINESS COMMITTEE

ARTHUR A. BAKER (1934)
ALBERT L. BEEKLY (1934)
FRANK R. CLARK (1935)
H. E. CRUM (1935)
JOSEPH A. DAWSON (1935)
C. E. DOBBIN (1935)
JAMES TERRY DUCE (1935)
WALTER A. ENGLISH (1934)
H. B. FUQUE (1935)
M. W. GRIMM (1935)
S. A. GROGAN (1935)
WILLIAM B. HEROY (1934)
JOHN F. HOSTERMAN (1935)
EDGAR KRAUS (1935)
FREDERIC H. LAHEE (1934)
ROLAND W. LAUGHLIN (1935)
THEODORE A. LINK (1935)
R. T. LYONS (1935)
ROY G. MEAD (1935)
A. F. MORRIS (1935)
WILLIAM M. NICHOLLS (1934)
PHILIP E. NOLAN (1935)
L. W. ORYNSKI (1934)
CLARENCE F. OSBORNE (1935)
E. E. ROSAIRE (1934)
GEORGE SAWTELLE (1934)
L. C. SNIDER (1934)
J. D. THOMPSON (1934)
WALLACE C. THOMPSON (1935)
PAUL WEAVER (1935)
G. H. WESTBY (1934)
E. A. WYMAN (1935)

RESEARCH COMMITTEE

DONALD C. BARTON (1936), *chairman*, Petroleum Building, Houston, Texas
M. G. CHENEY (1934)
K. C HEALD (1934)
F. H. LAHEE (1934)
H. A. LEY (1934)
R. C. MOORE (1934)
F. B. PLUMMER (1934)
C. E. DOBBIN (1935)
A. I. LEVORSEN (1935)
ALEX W. MCCOY (1935)
C. V. MILLIKAN (1935)
L. C. SNIDER (1935)
L. C. UREN (1935)
R. S. KNAPPEN (1936)
PARKER D. TRASK (1936)

REPRESENTATIVES ON DIVISION OF GEOLOGY AND GEOGRAPHY NATIONAL RESEARCH COUNCIL

R. C. MOORE (1933)
R. S. KNAPPEN (1934)

GEOLOGIC NAMES AND CORRELATIONS COMMITTEE

M. G. CHENEY, *chairman*, Coleman, Texas

JOHN G. BARTRAM
IRA H. CRAM
ALEXANDER DEUSSEN
B. F. HAKE
G. D. HANNA
A. I. LEVORSEN
C. L. MOODY
R. C. MOORE
ED. W. OWEN

TRUSTEES OF REVOLVING PUBLICATION FUND

ALEXANDER DEUSSEN (1933)
E. DEGOLYER (1934)
FRANK R. CLARK (1935)

TRUSTEES OF RESEARCH FUND

T. S. HARRISON (1933)
W. E. WRATHER (1934)
ALEX. W. MCCOY (1935)

FINANCE COMMITTEE

JOSEPH E. POGUE (1933)
E. DEGOLYER (1934)
W. E. WRATHER (1935)

COMMITTEE ON APPLICATIONS OF GEOLOGY

F. H. LAHEE, *chairman*, Box 2880, Dallas, Texas

WILLIAM H. ATKINSON
DONALD C. BARTON
FORD BRADISH
ARTHUR E. BRAINERD
H. A. BUEHLER
HAL P. BYBEE
W. F. CHISHOLM
HERSCHEL H. COOPER
CAREY CRONEIS
MARVIN LEE
S. E. SLIPPER
E. K. SOPER
LUTHER H. WHITE
R. B. WHITEHEAD

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), P. 752

Memorial

EUGENE CRITTENDEN TEMPLETON

The sweep of gray wings through gathering dusk. Shadows masking the broad terrain. Another day of his life-long quest for Truth drawn toward its close. Perhaps with tomorrow's dawning, yet a little more will be revealed to him in recompense for the long arduous hours in flight above that ever changing, ever the same inscrutable darkling land that now rises toward him. A sudden loom of trees, a single swerve of avoidance . . . with a flashing glory of full revealment the new day comes; his soaring spirit knows at last the hidden things. The years of brave single-hearted devotion, of rigorous self discipline, of joyous patient searching have found their fulfillment.

Born in Miles City, Montana, March 2, 1889, 'Gene Templeton spent his boyhood in a region which must have shaped his later years, for in 1906 he entered Stanford University, registered in the department of geology and mining, and four years later graduated as Bachelor of Arts. During 1911 and 1912 he took post-graduate work at Stanford and received the degree of Master of Arts in the latter year. During this period he also served as instructor in geology and mining.

In 1913 he assisted J. C. Branner in the preparation of that monumental work which crowned Branner's years of investigation in Brazil.

During the following two years, Templeton was associated with Harry R. Johnson in geologic field work mainly concerned with the petroleum-bearing regions of California, Montana, and western Canada. His unswerving fidelity to duty and to truth, his happy buoyant nature and fine companionship during this period, which was not always one of freedom from perplexities, make the remembrance of this all too short association a very dear one. But the call of a larger field of activity could not remain unanswered and in 1915, Templeton became resident geologist for the Intysh Corporation of London, at the Ridder Mines, Altai Mountains of Siberia. Here he remained until 1918 when, characteristically modest, he enlisted and served in France as a private soldier with Company C, 27th Engineers, U. S. A., until 1919.

During the balance of the year 1919, he was employed by Henry L. Doherty and Company with petroleum investigations in Honduras and Mexico and from 1920 to 1925 the richening character of the man and his unfolding powers found expression in extensive and delicate negotiations for the Sinclair Consolidated Oil Company in such widely separated spheres of action as Europe, China, Russia, and Venezuela.

In 1925 he entered the service of the Union Oil Company of California, made extensive geologic studies for that organization in Peru and Venezuela, and in 1926 became chief geologist for the Union National Petroleum Company at Caracas, Venezuela, remaining in that position until 1930, when he returned to California as geologist for the Union Oil Company.

His death occurred in Texas on November 21, 1932, near the close of a day's flight above a region, the geologic character of which, in the line of duty, he had been investigating for his company.

HARRY R. JOHNSON

LOS ANGELES, CALIFORNIA
APRIL 26, 1933

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 17, NO. 6 (JUNE, 1933), PP. 753-755

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

This department of personal news is of great use and interest to all members who read the *Bulletin*. Many have expressed their appreciation of it, but relatively few contribute to it,—possibly because of modesty. In order to avoid possible errors of printing items obtained from second-hand sources, it is hoped that members will keep headquarters informed of their own changes of address or occupation and professional activities of the kind which they like to read about other members. Send in your own items.

SIDNEY PAIGE, of 2911 Thirty-Third Street, N. W., Washington, D. C., has been employed as geological adviser to the Turkish Government.

WILLIS STORM has opened a consulting office at 1730 Milam Building, San Antonio, Texas.

MYRON C. KIESS has been transferred from the eastern division of the Pure Oil Company, at Newark, Ohio, to the Tulsa office of that company.

PHILIP S. SCHOENECK is district geologist for the Atlantic Oil Producing Company at Laredo, Texas. He was formerly in the Dallas office.

DJEVAD EYOUB, 302 Furr Drive, San Antonio, Texas, sailed the latter part of April for Ankara, Turkey, where he will again advise the government in matters of petroleum exploration and development. His address is Iktisat Vekaleti.

ERNEST OBERING, district geologist for the Shell Petroleum Corporation, has been transferred from Roswell, New Mexico, to San Angelo, Texas.

FRED H. KAY, formerly of the Pan-American Transport Company, may now be addressed at the Standard Oil Company of New Jersey, 26 Broadway, New York City.

J. R. REEVES, district manager of the Penn-York Natural Gas Corporation, announces the removal of its offices from Elmira, New York, to Coudersport, Pennsylvania.

JOHN M. HERALD, consulting geologist of Tulsa, is spending the summer at Cleo Springs, Oklahoma.

CLEO W. ECKENWILER, geologist for the Darby Petroleum Corporation, has been transferred from Tulsa, Oklahoma, to San Antonio, Texas.

ROLF ENGLEMAN, formerly at Matanzas, Cuba, is now at 711 Juniper Lane, Norman, Oklahoma.

WILLIAM C. IMBT, formerly of 324 Braeside Avenue, Stroudsburg, Pennsylvania, is now with the Illinois State Geological Survey, at Urbana.

Recent talks before the Tulsa Geological Society were the following: "Determination of Velocities in Arbuckle Limestone and Tishomingo Granite," by R. L. HARDING, of the Geophysical Research Corporation, Tulsa; and "Origin of the Shoestring Sands of Greenwood and Butler Counties, Kansas," by N. W. BASS, United States Geological Survey, Wichita. The society held its annual picnic and dance at Mohawk Park, Tuesday, April 25.

JOHN E. GALLEY, formerly teaching geology at Louisiana State University at Baton Rouge, is now employed in the geological department of the Shell Petroleum Corporation at Tulsa.

WARD C. BEAN, recently in the geological department of the Shell Petroleum Corporation at Tulsa, is working in Roumania. His address is Astra Romana, Campini, Roumania.

C. H. HARRIS, formerly part-time instructor in geology at Oklahoma University at Norman, is working for the Shell Petroleum Corporation with headquarters at Tulsa.

A meeting of the Appalachian Geological Society at the University of Kentucky, Lexington, on April 8, was attended by members from Ohio, Kentucky, and West Virginia. The following papers were presented.

"Nature and Mechanics of Low-Angle Overthrusting as Illustrated by the Cumberland Overthrust Blocks," by JOHN L. RICH, of the University of Cincinnati.

"Occurrence and Structure of the St. Peter and Cotter Formations as Revealed by Deep Test Wells on the Cincinnati Arch," by A. C. MCFARLAN and R. P. MEACHAM, of the University of Kentucky.

"The Work of the Kentucky Department of Agriculture with Reference to Coals and Oil Shales," by C. S. CROUSE, of the University of Kentucky.

"Relation of Fault Systems to Major Uplifts in the Appalachian, Ozark and Gulf Coal Regions," by W. H. BUCHER, of the University of Cincinnati.

On May 4–7, the Appalachian Society enjoyed a field trip to the Pine Mountain, Big Stone Gap, and Cumberland Gap localities of Kentucky and Virginia. The president, COLEMAN D. HUNTER, Kentucky-West Virginia Gas Company, Ashland, Kentucky, had charge of arrangements.

R. W. BRAUCHLI, of the Anderson Prichard Oil Corporation, Oklahoma City, Oklahoma, has a brief article in German on "Increasing the Production of Wells by Means of Chemical Solutions" in *Petroleum Zeitschrift* for April 5, 1933.

BROKAW, DIXON, GARNER, and MCKEE, engineers and geologists, of 120 Broadway, New York City, have transferred the office which they have maintained for the past six years at Shreveport, Louisiana, to Houston, Texas. DUGALD GORDON, who has been in charge since the offices were opened, moved to Houston, May 1.

RALPH O. RHOADES, formerly of Carthage, Missouri, may now be addressed in care of The Gulf Companies, Gulf Building, Pittsburgh, Pennsylvania.

W. D. CHAWNER has changed his address from Apartado 10, Matanzas, Cuba, to 969 East State Street, Ithaca, New York.

R. A. STEINMAYER has been retained by the Attorney General's office of the State of Louisiana as a geologic expert witness on the Lake Peigneur, Louisiana, case.

A. G. NANCE, R. B. KERBOW, and W. R. VANCE, all of the Gulf Production Company, Fort Worth, Texas, have been transferred to the Gulf Research and Development Corporation, Drawer K, Oakland Station, Pittsburgh, Pennsylvania. The Gulf Company at Fort Worth has changed its address from Box 737 to Box 1290.

THEODORE A. LINK is returning to Calgary, Alberta, Canada, to resume his position with the Imperial Oil, Limited, of Canada. During the past six

months he has been preparing exhibits for the Petroleum Industry for "A Century of Progress," 1933, Chicago.

The Pure Oil News, Chicago, Vol. 15, No. 10 (March, 1933), contains an article entitled "Oil Industry Preparing Fine Exhibits for World's Fair," by IRWIN E. LAMP, illustrated with a photograph of THEODORE A. LINK, geologist of the Imperial Oil Company, Ltd., of Canada, under whose direction the geological and producing phase of the story of petroleum has been arranged in "A Century of Progress" on display at Chicago this summer.

DONALD C. BARTON, Houston, Texas, has a paper entitled "The Iberian Structural Axis," in the April-May, 1933, issue of *The Journal of Geology*.

W. C. BLACKBURN, geologist, Humble Oil and Refining Company, has been transferred from Corpus Christi to Bastrop, Texas.

James FITZGERALD, JR., geologist with the Skelly Oil Company, has been transferred from Tulsa, Oklahoma, to Midland, Texas.

C. E. VAN ORSTRAND, of the United States Geological Survey, at Washington, and E. HEITHECKER, of the United States Bureau of Mines, at Shreveport, Louisiana, recently recorded the temperatures in wells in the Zwolle field, Sabine Parish, Louisiana. The Bureau of Mines is preparing a report on Zwolle.

W. P. JENNY, consulting geologist and geophysicist, of Dallas, Texas, spoke on "Structural Trends in Florida," before the Houston Geological Society in April.

FRANK BUTTRAM, of the Buttram Petroleum Corporation, Oklahoma City, is a new director of the Oklahoma Gas Corporation.

DWIGHT G. VEDDER is one of the purchasers of the Signal Oil and Gas Building in Los Angeles.

R. E. COLLOM is a director of the Southland Royalty Company, Ponca City, Oklahoma.

ROY M. BUTTERS is at 3236 Bryant Street, Denver, Colorado, engaged in consulting practice on gold and other mining prospects.

EVERETT CARPENTER, consulting geologist, of Amarillo, Texas, has an article on "Enormous Gas Wastage in the Panhandle Field under Proposed Conservation Legislation," in the *Oil and Gas Journal*, for April 27.

CHESTER D. WHORTON and H. ROGERS VAN GILDER are doing consulting work in the Pennsylvania-New York Oriskany gas area. They may be addressed at Box 83, Coudersport, Pennsylvania.

R. B. GRIGSBY, geologist for the Stanolind Oil and Gas Company, has been transferred from Shreveport to Baton Rouge, Louisiana.

JACKSON YOUNG, geologist for the United Gas System, formerly at Jackson, Mississippi, is now located at Monroe, Louisiana. His address is Box 1349.

The Michigan Academy of Science, Section of Geology and Mineralogy, of which W. A. THOMAS is chairman, held an excursion in stratigraphy, paleontology, and structural geology in the area within 50 miles of Lansing, May 27 and 28. The committee in charge was W. A. KELLY, chairman, FRANK LEVERETT, G. M. EHLERS, and R. B. NEWCOMBE.

H. A. BUEHLER was the guest of honor at a testimonial dinner at Rolla, Missouri, on May 10, in celebration of his 25th anniversary as state geologist of Missouri. He was appointed to this position in May, 1908, and has served

continuously since that time. Dr. Buehler's outstanding services to the State and, particularly, his participation in the development of the mineral industry of Missouri were reviewed by a number of speakers.

HAROLD C. VANDERPOOL, formerly of the geological staff of the Rycade Corporation at Houston, Texas, read a paper, "Notes on the Stratigraphy of the Gulf Coast Region," before the Tulsa Geological Society, May 15, and PARKER D. TRASK, of the United States Geological Survey at Washington, D. C., talked on "Source Beds" before the Society, May 18.

VICTOR BARLOW is engaged in field geology and petroleum engineering for the Bardeen Petroleum Company, Ltd., Los Angeles, California.

ROY LEBKICHER, formerly of Great Falls, Montana, is now located at 225 Bush Street, San Francisco, California.

FRANK G. PARRIS has changed his address from 50 West Broad Street, Columbus, Ohio, to 1516 Highland Drive, Charleston, West Virginia.

The American Institute of Mining and Metallurgical Engineers will hold a regional meeting at Chicago, June 26–30, in connection with A Century of Progress. The Hotel Stevens is headquarters. June 28 is Engineers' Day at the fair.

The thirteenth annual meeting of the Society of Economic Geologists will be held at Princeton University, Princeton, New Jersey, July 7–8.

The tenth annual field trip sponsored by the Shreveport Geological Society will cover the Jackson and Oligocene formations exposed in Caldwell and Catahoula parishes, Louisiana. The trip will begin at the Frances Hotel, Monroe, Louisiana, on Saturday morning, July 8. Bus transportation will be furnished throughout the trip. After completion of the first day's trip, return will be made to Monroe, from which point the second day's trip to additional localities will be made on July 9. A pamphlet containing maps, stratigraphic sections, and general discussion will be furnished. A nominal fee to cover cost of bus transportation will be charged. For further information, write to D. N. JOLLEY, 203 Ward Building, Shreveport, Louisiana.

The sixteenth session of the International Geological Congress will be held at Washington, D. C., July 22–29.

The price of a card in the professional directory of the *Bulletin* has been reduced from $25.00 to $15.00 per year (12 insertions), effective with new cards and with renewals at the expiration of present contracts.

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

L. C. SNIDER, *Editor*

ASSOCIATE EDITORS

GENERAL	K. C. HEALD, The Gulf Companies, Pittsburgh, Pa.
	HUGH D. MISER, U. S. Geological Survey, Washington, D. C.
	THERON WASSON, Room 2308, 35 E. Wacker Drive, Chicago, Ill.
GEOPHYSICS	B. B. WEATHERBY, Geophysical Research Corp., Tulsa, Okla.
APPALACHIAN	
North	JOHN R. REEVES, Penn-York Natural Gas Corp., Coudersport, Pa.
South	WILLIAM O. ZIEBOLD, 1572 Virginia Street, Charleston, W. Va.
NORTH CENTRAL STATES	W. A. THOMAS, The Pure Oil Company, Saginaw, Mich.
KANSAS	ANTHONY FOLGER, Gypsy Oil Company, Wichita, Kan.
OKLAHOMA	ROBERT H. DOTT, 1521 South Yorktown Avenue, Tulsa, Okla.
	GEORGE O. WILLIAMS, 2850 W. Twentieth, Oklahoma City, Okla.
TEXAS	
North and Central	M. G. CHENEY, Coleman, Tex.
Northeastern	E. A. WENDLANDT, Humble Oil and Refining Company, Tyler, Tex.
Panhandle	VICTOR E. COTNER, Columbian Carbon Company, Amarillo, Tex.
San Antonio	CHARLES H. ROW, Sun Oil Company, San Antonio, Tex.
Permian Basin	D. E. LOUNSBERY, Phillips Petroleum Corporation, San Angelo, Tex.
GULF COAST	DONALD C. BARTON, Petroleum Building, Houston, Tex.
	L. P. TEAS, Humble Oil and Refining Company, Houston, Tex.
ARKANSAS AND NORTH LOUISIANA	C. L. MOODY, Ohio Oil Company, Shreveport, La.
ROCKY MOUNTAIN	C. E. DOBBIN, 523 Customhouse Building, Denver, Colo.
CALIFORNIA	W. D. KLEINPELL, Box 1131, Bakersfield, Calif.
	W. S. W. KEW, Standard Oil Company, Los Angeles, Calif.
FOREIGN	
General	MARGARET C. COBB, Room 2703, 120 Broadway, New York, N. Y.
Europe and Mediterranean	W. P. HAYNES, 68 Pall Mall, London, S.W. 1, England
Canada	B. F. HAKE, Nordon Corporation, Ltd., Calgary, Alberta

J. P. D. HULL, *Business Manager*

VOLUME 17
JANUARY—DECEMBER 1933

PART 2

PAGES 757-1567

ASSOCIATION HEADQUARTERS
OFFICE OF THE BUSINESS MANAGER
BOX 1852, TULSA, OKLAHOMA

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

OFFICERS FOR THE YEAR ENDING MARCH, 1934

FRANK RINKER CLARK, *President*
Tulsa, Oklahoma

FREDERIC H. LAHEE, *Past-President*
Dallas, Texas

GEORGE SAWTELLE, *Vice-President*
Houston, Texas

WILLIAM B. HEROY, *Secretary-Treasurer*, New York, N. Y.

L. C. SNIDER, *Editor*, New York, N. Y.

DISTRICT REPRESENTATIVES

(Representatives' terms expire immediately after annual meetings of the years shown in pa entheses.

Amarillo:
J. D. Thompson, Jr. (1934), Amarillo, Tex.
Appalachian:
H. E. Crum (1935), Charleston, W. Va.
Canada:
Theodore A. Link (1935), Calgary, Canada
Capital:
Arthur A. Baker (1934), Washington, D. C.
Dallas:
L. W. Orynski (1934), Dallas, Tex.
East Oklahoma:
Albert L. Beekly (1934), Tulsa, Okla.
R. T. Lyons (1935), Tulsa, Okla.
A. F. Morris (1935), Bartlesville, Okla.
Fort Worth:
H. B. Fuqua (1935), Fort Worth, Tex.
Great Lakes:
Theron Wasson (1933), Chicago, Ill.
Houston:
Paul Weaver (1935), Houston, Tex.
Mexico:
S. A. Grogan (1935), Tampico, Mexico
New Mexico:
Edgar Kraus (1935), Carlsbad, New Mexico
New York:
James Terry Duce (1935), New York, N. Y.
Pacific Coast:
Walter A. English (1934), Los Angeles, Calif.
Roy G. Mead (1935), Los Angeles, Calif.
Clarence B. Osborne (1935), Los Angeles, Calif.
Rocky Mountains:
C. E. Dobbin (1935), Denver, Colo.
San Antonio:
Joseph M. Dawson (1935), San Antonio, Tex.
Shreveport:
M. W. Grimm (1935), Shreveport, La.
South America:
Philip E. Nolan (1935), Maracaibo, Venezuela, S.A.
So. Permian Basin:
John F. Hosterman (1935), San Angelo, Tex.
West Oklahoma:
Roland W. Laughlin (1935), Oklahoma City, Okla.
Wichita:
E. A. Wyman (1935), Wichita, Kan.
Wichita Falls:
William M. Nicholls (1934), Wichita Falls, Tex.

DIVISION REPRESENTATIVES

Paleontology and Mineralogy:
Herschel L. Driver (1933), Los Angeles, Calif.
Norman L. Thomas (1933), Fort Worth, Tex.

Geophysics:
E. E. Rosaire (1934), Houston, Tex.
G. H. Westby (1934), Tulsa, Okla.

OFFICERS FOR THE YEAR ENDING MARCH, 1933

President: FREDERIC H. LAHEE

Past-President: LOVIC P. GARRETT

Vice-President: ROBERT J. RIGGS

Secretary-Treasurer: WILLIAM B. HEROY

Editor: R. D. REED

COPYRIGHT 1933 BY
THE AMERICAN ASSOCIATION OF
PETROLEUM GEOLOGISTS

PUBLISHED
MONTHLY

Composed and Printed by
George Banta Publishing Company
Menasha, Wisconsin, U.S.A.

CONTENTS OF VOLUME 17

PART 2

NUMBER 7

EAST TEXAS OIL FIELD. H. E. Minor and Marcus A. Hanna . . 757
DISTRIBUTION OF OIL POOLS IN KANSAS IN RELATION TO PRE-MISSISSIPPIAN STRUCTURE AND AREAL GEOLOGY. John L. Rich 793
DRISCOLL POOL, DUVAL COUNTY, TEXAS. I. R. Sheldon . . . 816
PRESERVATION OF OIL DURING EROSION OF RESERVOIR ROCKS. George Edwin Dorsey 827
GEOLOGICAL NOTES
Classification and Nomenclature of Rock Units . . . 843
Permian Algal Reef in South Park, Colorado, *J. Harlan Johnson* 863
Overturned Beds in Arbuckle Mountains, Oklahoma, *Robert H. Dott*. 865
DISCUSSION
Review of Tertiary Stratigraphy of Louisiana, *Hugh D. Miser and Alexander Deussen* 871
REVIEWS AND NEW PUBLICATIONS 872
THE ASSOCIATION ROUND TABLE 874
AT HOME AND ABROAD 875

NUMBER 8

GEOLOGY AND OCCURRENCE OF NATURAL GAS IN AMARILLO DISTRICT, TEXAS. Victor Cotner and H. E. Crum 877
RÔLE OF DIASTROPHISM IN TOPOGRAPHY OF CORPUS CHRISTI AREA, SOUTH TEXAS. W. Armstrong Price 907
PARADOX FORMATION OF EASTERN UTAH AND WESTERN COLORADO. A. A. Baker, C. H. Dane, and John B. Reeside, Jr. . . 963
SIMPLE PRINCIPLES OF EFFICIENT OIL-FIELD DEVELOPMENT. H. D. Wilde, Jr. and F. H. Lahee 981
GEOLOGICAL NOTES
Cretaceous Sediments in Crowleys Ridge, Southeastern Missouri, *F. E. Matthes* 1003
Clastic Facies and Faunas of Monterey Formation, California, *J. Edmund Eaton* 1009
REVIEWS AND NEW PUBLICATIONS 1016
THE ASSOCIATION ROUND TABLE 1019
MEMORIAL
Reichie S. Stelfox, *P. B. Leavenworth* 1021
AT HOME AND ABROAD 1022

NUMBER 9

MECHANICS OF FORMATION OF SALT DOMES WITH SPECIAL REFERENCE TO GULF COAST SALT DOMES OF TEXAS AND LOUISIANA. Donald C. Barton 1025
OIL FIELDS OF POLAND, GEOLOGICAL AND STATISTICAL SUMMARY. Charles Bohdanowicz 1084
PSEUDO-TECTONIC STRUCTURES. W. G. Woolnough 1098
STUDIES IN PALEOGEOLOGY. A. I. Levorsen 1107
GEOLOGICAL NOTES
Influence of Speed of Migration of Oil on Water Encroachment at Casmalia, California, *William W. Porter, II* . . 1133
New Major Oil Fields of Apsheron Peninsula, U.S.S.R., *Basil B. Zavoico* 1136
Sixteenth International Geological Congress, *Robert H. Dott* . 1139
RESEARCH NOTES 1146
REVIEWS AND NEW PUBLICATIONS 1148
Recent Publications 1153
THE ASSOCIATION ROUND TABLE
Supplementary Membership List, September 1, 1933 . . 1154
MEMORIAL
Allan Eugene Reiff, *Allen W. Tillotson* 1156
AT HOME AND ABROAD 1157

NUMBER 10

GEOLOGY OF KETTLEMAN HILLS OIL FIELD, CALIFORNIA. G. C. Gester and John Galloway 1161
SURFACE FRACTURE SYSTEM OF SOUTH TEXAS. Donald C. Barton . 1194
SUBSURFACE CONCENTRATION OF CHLORIDE BRINES. William L. Russell 1213
GENERATION OF OIL IN ROCKS BY SHEARING PRESSURES. IV–V. FURTHER STUDIES OF EFFECTS OF HEAT ON OIL SHALES. W. P. Rand 1229
CONVERSION OF FATTY AND WAXY SUBSTANCES INTO PETROLEUM HYDROCARBONS. W. F. Seyer 1251
GEOLOGICAL NOTES
Igneous Intrusives in Silver City Area, Kansas, *Samuel Weidman* 1268
DISCUSSION
Preservation of Oil During Erosion of Reservoir Rocks, *Joseph S. Irwin, George Edwin Dorsey, and L. C. Case* . . . 1271
Reynosa Problem of South Texas, and Origin of Caliche, *W. Armstrong Price* 1277
REVIEWS AND NEW PUBLICATIONS 1282
AT HOME AND ABROAD 1287

NUMBER 11

CORRELATION OF JACKSON GROUP IN TEXAS, WITH NOTES ON FRIO AND VICKSBURG. Alva Christine Ellisor 1293
ZONE OF EXOGYRA CANCELLATA TRACED TWENTY-FIVE HUNDRED MILES. L. W. Stephenson 1351
SUGARLAND OIL FIELD, FORT BEND COUNTY, TEXAS. W. B. McCarter and P. H. O'Bannon 1362
GEOLOGICAL NOTES
Definition of Cocoa Sand Member of Jackson Formation, *C. Wythe Cooke* 1387
Beekite in Tertiary Oil-Bearing Formations of Southern Ecuador, *George Sheppard* 1388
Island in Permian Sea, *John Emery Adams* 1391
REVIEWS AND NEW PUBLICATIONS 1394
THE ASSOCIATION ROUND TABLE 1399
MEMORIAL
Harry Mayo Andreen, *E. O. Markham* 1401
AT HOME AND ABROAD 1403

NUMBER 12

VIOLA LIMESTONE, PRIMARILY OF ARBUCKLE AND WICHITA MOUNTAIN REGIONS, OKLAHOMA. Charles E. Decker 1405
OIL AND OIL STRUCTURES IN OKLAHOMA-KANSAS ZINC-LEAD MINING FIELD. George M. Fowler 1436
GULF COAST GEOSYNCLINE. Donald C. Barton, C. H. Ritz, and Maude Hickey 1446
RACCOON BEND OIL FIELD, AUSTIN COUNTY, TEXAS. L. P. Teas and Charis R. Miller 1459
OVERHANGING SALT ON DOMES OF TEXAS AND LOUISIANA. Sidney A. Judson and R. A. Stamey 1492
JAMIN EFFECT IN OIL PRODUCTION. Randall Wright 1521
CLAY DIKES IN REDSTONE COAL, WEST VIRGINIA AND PENNSYLVANIA. Paul H. Price 1527
DISCUSSION
Reynosa Problem of South Texas, and Origin of Caliche, *Charles Laurence Baker* 1534
Coastal Plain Stratigraphic Nomenclature 1535
Geology of Blue Springs Gas Field, Jackson County, Missouri, *Glenn G. Bartle* 1536
REVIEWS AND NEW PUBLICATIONS 1538
THE ASSOCIATION ROUND TABLE 1543
AT HOME AND ABROAD 1547
INDEX TO VOLUME 17 1551

ERRATA

Page 918, 3d new paragraph, lines 1–2: "behind" should be *between*.

Page 921, line 9: "depression" should be *outlet*.

Page 933, Fig. 9, line 6: "1920–22" should be *1902–22*.

Page 941, 3d paragraph, line 7: "and bone" should be *clay*.

Page 947, Fig. 14, line 2 from bottom: "current south" should be current *from* south.

Page 1009, faunal list of "*gastropoda:*" seven species, *Crassatellites* to *Corbula* inclusive, should be listed under *Pelecypoda*.